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DEVELOPMENT OF A HELIPORT CLASSIFICATION METHOD AND AN ANALYSIS--ETC(U)
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June 1981
Final Report

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16. Abstract

A helicopter performance related heliport classification method is developed which accomodates an applicable range of operating conditions and factors which impact helicopter performance. Dimensional values for use in planning both real estate and airspace surfaces are determined for application to the identified heliport classifications. Those values are incorporated into generalized guidelines for heliport planners to meet site-specific and non-standard operational conditions. Requirements for flight manual performance charts and published heliport information are also identified.

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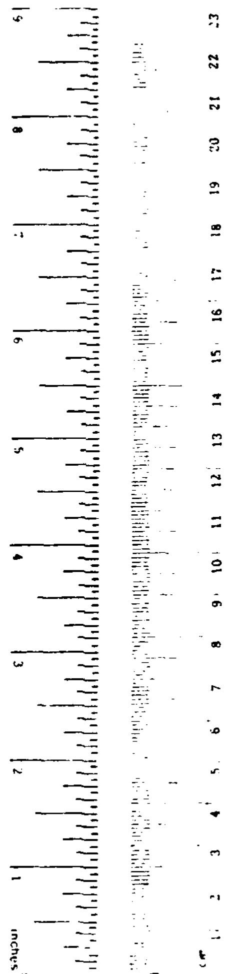
METRIC CONVERSION FACTORS

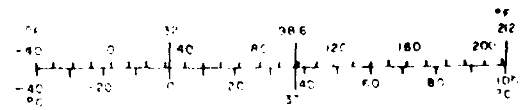
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS AND SYMBOLS

AGL	Above Ground Level
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
fpm	feet per minute
HIGE	Hover in-ground-effect
HMA	Heliport Maneuver Area
HOGE	Hover out-of-ground-effect
H-V	Height-Velocity
IFR	Instrument Flight Rules
IGE	In-Ground-Effect
IMC	Instrument Meteorological Conditions
ln	Logarithm (to the base e)
LGW	Light Gross Weight
MGW	Maximum Gross Weight
MLS	Microwave Landing System
NASA	National Aeronautics and Space Administration
OEI	One Engine Inoperative
OGE	Out-of-Ground-Effect
P.A.	Pressure Altitude
PAR	Precision Approach Radar
RFM	Rotorcraft Flight Manual
STD	Standard (referring to standard day temperatures)
TERPS	Terminal Instrument Procedures
TERPS Handbook	U.S. Standard for Terminal Instrument Procedures
TN	Technical Note
TOGW	Takeoff Gross Weight
TOSS	Takeoff Safety Speed
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
V_y	Airspeed for Best Rate of Climb
WAT	Weight, Altitude, Temperature

INTRODUCTION

This study was undertaken to develop recommendations for a heliport classification system which is responsive to real estate and airspace needs appropriate to a variety of helicopters, their differing performance capabilities, and the impact of varying ambient enviornmental conditions.

The purpose of this report is to provide a basis for informed planning during the site selection and design of heliports. It documents development of the heliport classification method, and presents guidelines for heliport planners to determine the real estate and airspace requirements for the various helicopter performance levels which are identified herein.

Earlier research, reported in the Study of Heliport Airspace and Real Estate Requirements (Reference 1), reviewed and evaluated the real estate and airspace requirements as set forth in applicable U.S. heliport criteria. The primary source of criteria was the Heliport Design Guide (Reference 2) which is currently used by heliport planners. The study examined the suitability of criteria with respect to helicopter performance and various operational requirements at heliports. Among the recommendations resulting from that study were: a revised heliport classification scheme with corresponding changes to real estate and airspace criteria for instrument flight rules (IFR) operations; and helicopter performance chart standardization for flight manuals with specific data requirements.

The research effort documented in this report expands that revised classification scheme and offers guidelines for heliport planners in establishing the appropriate real estate and airspace. A helicopter performance related heliport classification method is developed which accommodates an applicable range of operating conditions and factors which impact helicopter performance. Dimensional values for use in planning both real estate and airspace surfaces are determined which relate to the identified heliport classifications. These values are incorporated into generalized guidelines for heliport planners to meet site-specific and non-standard operational

conditions. Requirements for flight manual performance charts and published heliport information are also identified.

This study has developed guidelines which should permit heliport planners to implement heliports that enable maximized productivity in relationship to pragmetic constraints. The guidelines offer planners the ability to evaluate the impact, on various helicopter performance classes, of site-specific conditions which limit the available real estate or do not allow optimum performance to be achieved. The guidelines developed in the course of this research are designed to maximize the productivity of helicopters. Unfortunately, dedication of the real estate and airspace necessary for this optimization of helicopters' utility may not always be practical and may, in some cases, be infeasible. The high costs of real estate, especially in some metropolitan areas, and existing terrain or structures, typically conflict with implementation of an ideal or optimum heliport design. Resulting compromises in heliport design will necessitate performance tradeoffs in subsequent helicopter operations.

The very performance-maneuver characteristics which make helicopters unique can also provide a solution to the problem of limited real estate. In this regard, performance capability charts for use by helicopter pilots can provide a "go-no-go" system in the cockpit which would provide a basis for trading off productivity to enable successful operation at even the most restrictive heliports.

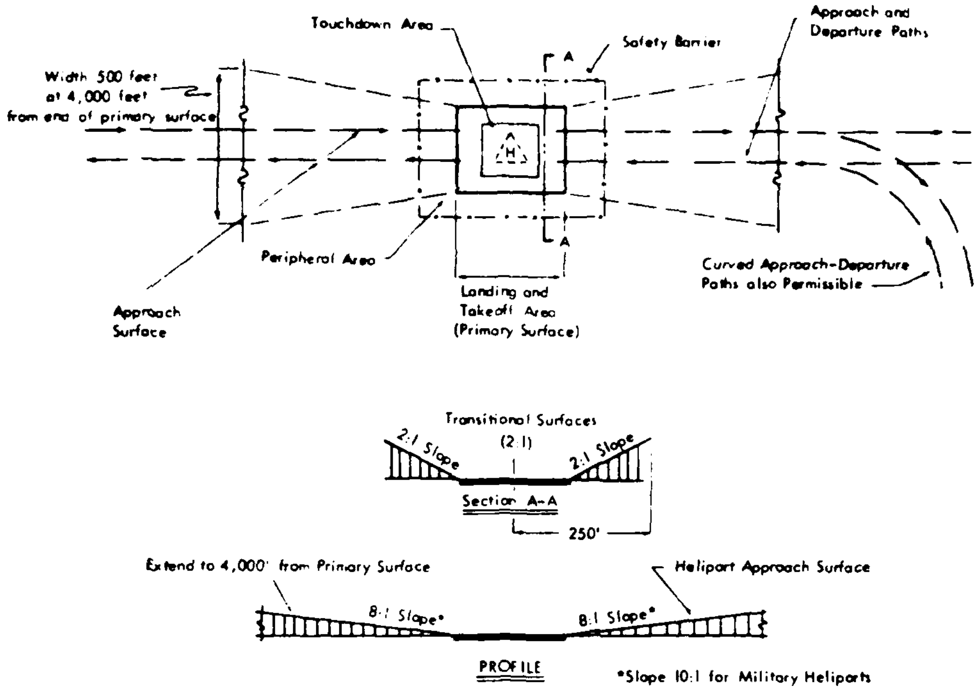
This study necessarily documents and analyzes the performance capabilities and limitations of a broad range of currently certified and operating helicopters, and establishes recommended real estate and airspace responsive to the limiting conditions of both maximum gross weight and critical ambient environmental conditions applicable to specific sites. This is done to identify and establish the change in capabilities of helicopters which result from high gross weight operations, and which require greater heliport real estate and/or airspace. Beyond that, improved performance and reduced heliport requirements are achieved through reduced operating weights of helicopters.

Advisory Circular AC150/5390-1B, Heliport Design Guide (Reference 2), is currently the primary source of guidance for heliport planners. The document establishes basic obstacle surface criteria, and recommends minimum dimensional values and general operational considerations for heliports. Its criteria and recommendations are thoroughly discussed in Reference 1. By way of review, Figure 1 depicts the imaginary surfaces for heliports as prescribed in the Heliport Design Guide. The surfaces shown in Figure 1 depict the current minimum requirements for heliports in the U.S., regardless of site-specific ambient conditions or the type of helicopters to use the facility.

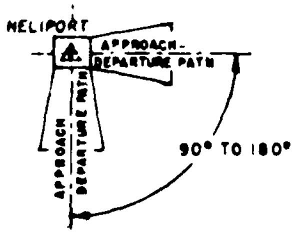
Heliport planners are faced with the ultimate task of determining the amount of real estate and airspace needed for anticipated operations. The easiest approach would be to provide as much real estate and as shallow an obstacle gradient as physically possible. However, providing too much real estate can involve unnecessary or prohibitive costs; and not allowing enough can eliminate much of the utility of the heliport, or cause it to fall short of providing an appropriate level of safety.

The decision-making situation must, then, effectively result in a cost-benefit assessment. Some of the factors which influence that decision process include: cost or availability of real estate; the type of helicopters to use the facility and their respective performance capabilities; the expected ambient environmental conditions at the proposed site and their effect on helicopter performance for the anticipated mission configurations (i.e., weight, etc.); and any special operational considerations which might be occasioned by requirements contained in the Federal Aviation Regulations (FAR), state and local ordnances, or prudential regulations.

In resolving the issue of real estate requirements, the planner must work closely with the potential operators; not only to understand their performance capabilities, but to ensure that the ultimate decision supports sufficient utility such that the resulting heliport design does not intolerably limit their mission configurations but still protects the public interest. The helicopter operators, however, do not now always have all the information they



ACCEPTABLE RANGE OF ANGLES BETWEEN APPROACH-DEPARTURE PATHS
WHEN MORE THAN ONE APPROACH-DEPARTURE PATH IS PROVIDED



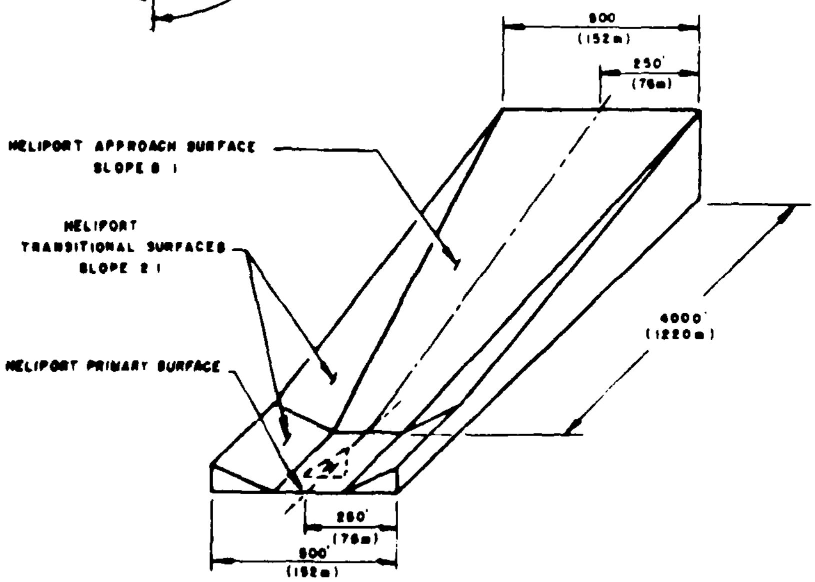


Figure 1. Imaginary Surfaces for Heliports.

need in their Rotorcraft Flight Manuals (RFM) and other documentation to permit an adequate assessment of their capabilities with respect to obstacle clearances provided by existing real estate and airspace.

Thus, the solution to be offered by the Federal Aviation Administration (FAA) must include not only performance-oriented heliport planning guidelines, but appropriate performance data in flight manuals. In providing suitable guidance to heliport planners, both a heliport classification scheme must be introduced, and manufacturers must have guidance as to the performance data required by the helicopter operators who will ultimately use the heliport facilities.

HELIPORT OPERATIONAL MODELS AND FLIGHT PROFILES

Before analyzing helicopter performance requirements and capabilities, it is useful to identify the operational environment within which the helicopter is expected to perform. For the purposes of this research, the operational models described herein are restricted to those flight phases with relatively close proximity to the heliport itself -- i.e., to terminal operations between the surface and 500 feet above ground level (AGL).

Baseline flight profiles are offered which characterize the flight phases of interest, and the various types of operations to which they apply are discussed. To better understand those flight phases, two concepts introduced in Reference 1 should briefly be reviewed: Heliport Maneuver Area (HMA) and Balanced Heliport. Their definitions are restated below.

HELIPORT MANEUVER AREA: An obstacle-free level area, surrounding or contiguous to the takeoff and landing area, to be used for the necessary in-ground-effect maneuvering of helicopters during takeoff/departure and approach/landing. It provides real estate for the acceleration and deceleration of using helicopters, and varies in size.

BALANCED HELIPORT: With respect to engine failure procedures for multi-engine helicopter operations, a heliport with a maneuver area of sufficient size and appropriate quality of surface to permit an aborted takeoff following an engine failure at the most critical decision point for all Transport Category A helicopters authorized to use the facility.

The above definitions are not intended to restrict the operational models presented herein. Rather, they were introduced to expand the flight phases of one of three flight profiles to be discussed.

Baseline Flight Profiles

Three distinctly different flight profiles can be developed for heliport operations, which identify all potential terminal maneuvers and flight phases applicable to both visual flight roles (VFR) and IFR operations. These

profiles are presented in Figure 2. The operational model for a given heliport can contain various combinations of flight phases, from any or all of the profiles, depending on site-specific conditions and the capabilities of the helicopters which would use the heliport. The subject profiles represent the possible operational needs of helicopters, and reflect the various requirements of applicable certification and operating regulations of the FAR (References 3 through 8).

Figure 2A shows the Horizontal Flight Profile, depicting the use of a significantly large Heliport Maneuver Area to support flight operations when hover-out-of-ground effect (HOGE) is not possible. For takeoff, a vertical lift off to an in-ground-effect (IGE) hover is made followed by acceleration IGE to the airspeed for best rate of climb (V_y). Upon reaching V_y, climb is initiated and sustained until reaching cruising altitude. For landing, approach is made at a comfortable airspeed and descent gradient until approaching the ground plane. The aircraft is leveled off IGE and decelerated to an IGE hover within the confines of the Heliport Maneuver Area. A variation of this technique, which may be used when the HMA surface is suitable, is a running landing.

Figure 2B shows the Direct Flight Profile, depicting takeoff and landing without the use of an appreciable HMA. The helicopter must be capable of HOGE to utilize this profile. For takeoff, a vertical lift off to an IGE hover is made followed by an accelerating climb. The needed initial climb gradient is sustained until clear of controlling obstacles. Then acceleration to V_y is resumed (if necessary) and climbout is continued at V_y. Landing approach is initiated at a comfortable airspeed and descent gradient with deceleration accomplished along the flight path to an IGE hover. When hovering performance capability is marginal, the Direct Profile landing may be used by completing a decelerating approach to touchdown on the landing surface. In the latter procedure, care must be used to ensure that sink rate is controlled throughout the approach and that hover attitude and nearly zero groundspeed are attained at the moment of touchdown.

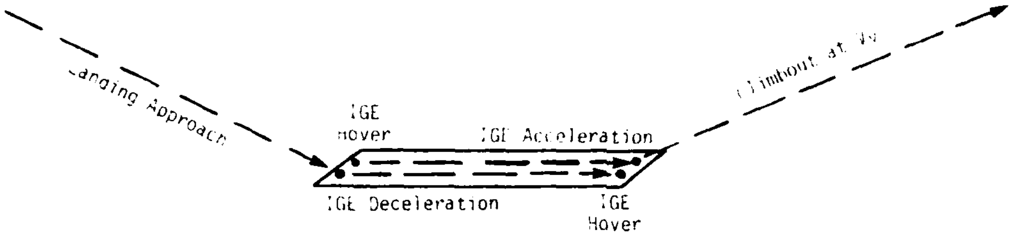


Figure 2A. Horizontal Flight Profile.

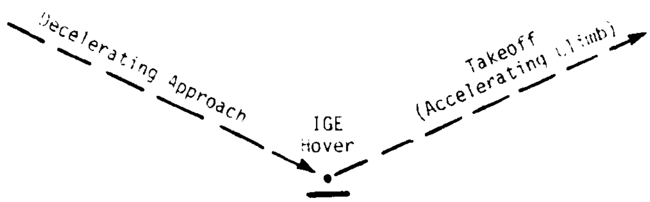


Figure 2B. Direct Flight Profile.

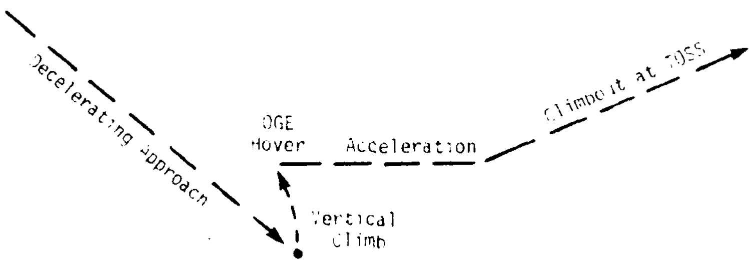


Figure 2C. Vertical Flight Profile.

Figure 2. Flight Profiles for Heliport Operations.

Figure 2C shows the Vertical Flight Profile, defined for use by Transport Category A helicopters to ensure safe operation in the event of engine failure when operating from a heliport lacking an adequately sized HMA. For takeoff, a near vertical climb is initiated with slight backwards motion to retain visual contact with the heliport landing area. Climb is continued until reaching a critical decision height from which acceleration into forward flight is initiated. Failure of one engine before reaching the decision height results in a decision to immediately land. Failure of one engine after initiating the acceleration results in a decision to continue the takeoff, descending if necessary to attain takeoff safety speed (TOSS) for climbout. For landing, the approach profile is similar to the Direct Profile landing, but approach beyond the critical decision point is continued directly to touchdown on the landing surface as described in the procedure for marginal hover capability. Utilization of the Vertical Profile procedure generally requires reduction in takeoff gross weight (TOGW) below the maximum certified TOGW which would be based on Horizontal Profile procedural performance capability.

The various flight maneuvers depicted are well documented and discussed in Reference 1. Of importance to this study is the fact that each flight profile holds forth a clear option for various levels of performance from the using helicopters, which result in different requirements for real estate and airspace. Further, the profiles presented do not represent the only available choices. Rather some blending or combination of phases of one profile can be made with others. A case in point would be the blending of Horizontal and Direct procedures when the HMA permits some measure of IGE acceleration, but not enough to reach V_y as in the strict Horizontal case.

In heliport planning, the choice of flight profiles or combinations thereof, with attendant implications for real estate and aircraft performance will vary with the type of flight operations. Consideration must therefore be given to such conditions as night, instrument or failure state operations and the impact of operating regulations. These are addressed in the following pages.

Instrument Operations

Given established minimum ceiling and visibility requirements, current instrument flight profiles generally require an increase in real estate and airspace from the baseline VFR requirements. The exception is the case of non-precision instrument approaches. There are three instrument flight phases of interest: Non-Precision approach/landing, precision approach/landing, and takeoff/departure. The real estate and airspace criteria contained in Reference 2 are supplemented or changed by the U.S. Standard for Terminal Instrument Procedures (TERPS), referred to here as the TERPS Handbook (Reference 9). Helicopter-Only criteria are established in Chapter 11 (Helicopter Procedures) of Reference 9.

A non-precision instrument approach/landing requires no additional real estate or airspace beyond the current, basic VFR requirements of the Heliport Design Guide. As reported in Reference 1, the procedures and obstacle clearances for non-precision approaches are fully compatible with the existing VFR surfaces at heliports.

Helicopter-Only precision instrument approaches are addressed only insofar as real estate and airspace criteria are established for Precision Approach Radar (PAR). They do require substantial increases in real estate and airspace through the obstacle surface requirements identified in the TERPS Handbook. The only potential alternative in the foreseeable future which could relax those requirements is the certification of slow or decelerating steep approaches using the Microwave Landing System (MLS) or other presently uncertified precision landing aide.

An instrument takeoff/departure presents a somewhat different problem, as there are no criteria established at present for real estate or obstacle surfaces under Chapter 11 of Reference 9. Requirements for real estate and airspace are otherwise determined by reviewing various regulations which pertain to either aircraft certification or flight operations, depending on which helicopter and the type of operation being conducted. Certification requirements such as minimum IFR airspeeds for the various helicopters

are contained in FAR Parts 27 and 29, while operational regulations are found in FAR Parts 91 or 127 and 135 and define applicable ceiling and visibility requirements.

Certain minimum IFR airspeed limitations imposed through the aircraft certification are documented in the Rotorcraft Flight Manual. These generate a requirement for sufficient real estate, given ceilings too low to permit climb and acceleration under visual meteorological conditions (VMC), to accelerate to at least a minimum IFR airspeed or minimum IFR climb speed from which a climbout can be initiated into instrument meteorological conditions (IMC). The actual climbout airspeed employed may vary within the allowable (certified) IFR airspeed envelope, but will most probably be at the recommended IFR climb airspeed published in the RFM. The rate of climb for those airspeeds determines climb gradients which can be used to define obstacle surfaces.

Night Operations

The factors introduced by night operations center around the potential absence or limits of visual cues for pilots. This suggests a possible need to increase the minimum size of Heliport Maneuver Areas for those heliports authorized for night operation. Where unmarked obstacles exist, shallower obstacle surface gradient criteria might be considered. This would be similar to the Canadian government's Night VFR heliport classification. (See Reference 1.)

Two other alternatives are available that would preclude the need for changing obstacle surfaces: final approach guidance and revised lighting requirements. The first, especially in the case of the visual approach slope indicator (VASI), could alleviate the need for revised lighting criteria. Otherwise, it is recommended that consideration be given to requiring lighting of obstacles that exceed a gradient of one-half the obstacle surface gradient from the edge of the heliport maneuver area for those heliports certified or approved for night operations.

Failure-State Operations

The underlying FAA philosophy is that obstacle protection, i.e., the establishment of obstacle surfaces and clearances, generally assumes normal operations. Although it has not been directly suggested that this applies primarily to Copter-Only procedures, it is believed that this is not the case for all airplane obstacle surfaces/clearances.

It is useful to recall the "Balanced Field Length" concept, which applies to certain multi-engine aircraft. The concept requires aircraft loading such that, with the Weight, Altitude and Temperature (WAT) conditions for takeoff combined with the runway length, and in the event of a single engine failure, the pilot will be able to either:

(1) abort the takeoff, and come to a full stop on the runway with engine failure prior to the decision speed; or

(2) continue the takeoff, and climb with one engine inoperative (OEI), such that a minimum altitude of 35 feet AGL is achieved over the departure threshold with an OEI climb established.

There is presently no such concept applied to heliport design; only a recommendation that suitable forced landing areas be made available along the approach-departure paths.

Impact of Operating Regulations

The various, pertinent operating regulations were reviewed to identify their impact on heliport requirements. Of interest were any vertical speed, airspeed, or other limitations which might dictate operations in a manner which requires some specific or additional amounts of real estate or airspace. The flight regulations of interest were FAR Parts 91, 127 and 135. Nothing was found which would impose specific requirements (in terms of numerical values) on the heliport planner, but responsibilities were clearly placed on pilots to varying levels.

Part 91 (General Operating Regulations) applies to all pilots, regardless of the type of operation, and it is the ultimate governing requirement after any other appropriate regulations have been complied with. Of importance to this research, it is the only one of the three Parts of interest which governs the privately owned, not-for-hire Corporate/Executive flight operations. It places no restrictions on helicopter pilots which would require real estate other than that recommended in the current Heliport Design Guide. It does direct in Paragraph 91.79 that, except for takeoff and landing, the helicopter will be flown at such an altitude and in such a manner that, in the event of an engine failure, it can be safely landed without harm to persons and property on the ground.

Part 127 applies to the handful of potential Scheduled Air Carrier operations which may use helicopters. Paragraph 127.81 calls out limitations in the Rotorcraft Flight Manuals which must be complied with, and which are required under the aircraft certification regulations. Paragraph 127.83 specifically requires that Transport Category B helicopters have safe forced landing areas available along the entire route. This suggests that planners contemplating scheduled Part 127 service should ensure the availability of forced landing areas early in the development process. Transport Category A goes further in that it sometimes requires heliport maneuver area sizes suitable for rejected takeoffs. This is because not all Transport Category A helicopters are certified for vertical departure procedures. Its requirements can be imposed through the FAA-directed Operations Specifications for either Part 127 or 135 operation.

Part 135 applies to the remaining Commercial Air Carrier or Air Taxi operators. It implies pilot responsibility even further than Part 91, although no specific operational limitations or restrictions are imposed. In Paragraph 135.229, Airport Requirements (which applies equally to heliports in a purely technical sense), it is stated that "no certificate holder will operate at any airport (heliport) unless it is adequate for the intended operation, considering the size, surface, obstructions and lighting."

The difficulty in applying the mandate here is that the pilot may or may not have the information needed to judge if his performance capability is of a

sufficient level that the heliport would in fact be adequate. This point is reviewed further in later discussions of helicopter performance charts.

Considerations for Future Improvements

Anticipated changes in helicopter capabilities, as well as heliport landing systems and facilities, suggest that heliports, designed for use by future helicopters, should require less real estate and airspace than is presently needed. As a means to accomodate expected improvements, it is recommended that performance charts be introduced now to satisfy pilots' requirements in determining helicopter capabilities with respect to any site-specific obstacle surfaces and maneuver areas.

A number of aircraft are already under various stages of development which may radically change heliport criteria of the future by virtue of introducing substantially different flight profiles. The Bell Helicopter Textron XV-15 currently undergoing NASA/Army evaluation uses tilt-rotor technology which allows it to convert in flight between a pure helicopter and a pure airplane mode. Additionally, the concept of using three engines in helicopter powerplant systems (currently applied in the French Aerospatiale Super Frelon and U.S. Sikorsky CH-53E) may find another subscriber as the British Westland EH-101 development program progresses.

In such cases, a vertical liftoff with an OGE transition to forward flight may become the preferred departure procedure. Especially in the case of three-engine helicopters, vertical approach and departure profiles could resolve much of the desire for minimum real estate, given sufficient excess power through the third engine.

ROLE OF HELICOPTER PERFORMANCE IN HELIPORT PLANNING

Given unlimited real estate and airspace for the heliport, there are no performance requirements (i.e., required capabilities) imposed on using helicopters beyond a need for hover in ground effect (HIGE). Rather, the performance requirements are replaced by the operating limitations of the helicopter -- primarily the weight, altitude and temperature conditions determined in the aircraft certification documents, and cited in the rotorcraft flight manual.

However, because there are limits to the real estate and airspace available, performance requirements or demands must at times be made on the using helicopters. This can take several forms, resulting in various approach-departure path gradients and/or heliport maneuver area sizes.

On the other hand, certain combinations of altitude and temperature can severely limit or reduce the performance capabilities (such as climb gradients) unless reductions in operating weight are made. Thus, to achieve one performance capability (steep climb or descent) may require a stringent performance limitation in terms of operating weight (payload).

This can present the heliport planner with the need to resolve a difficult issue. He must determine what is the best or acceptable balance between the performance capabilities required and those available.

Heliport Real Estate and Airspace Planning Decision

The balance introduced above underscores the bottom-line planning decision required to implement a heliport: "Determine a level of performance (requirement and capability) which is both practical and cost-effective."

Figure 3 portrays the major elements or considerations in the heliport planning decision with respect to the critical case of climb performance. Figure 3A depicts the full tradeoff regime available, while Figure 3B portrays the determination of an acceptable or practical tradeoff. The Maximum Gross Weight (MGW) line represents the highest productivity (payload) but results in the shallowest climb gradient -- and, consequently, the greatest real estate and airspace. The example assumes there is no capability for OGE hover, thus requiring a significantly large Heliport Maneuver Area. However, the example helicopter is capable of much greater performance (steeper climb gradient) at Light Gross Weight (LGW) but with little or no payload -- such as the minimum crew and fuel for a short flight plus reserves. Typically, the limiting LGW capability would consist of a steep, accelerating climb; but the LGW condition offers no utility or productivity in terms of payload.

What the heliport planner and the heliport user must do, is determine or agree upon a level of performance which is both affordable and sufficiently productive. This is represented in Figure 3B as the Practical Level, which results in accommodation of an acceptable amount of user capability (in terms of useful load) without requiring exorbitant amounts of real estate and airspace.

The problem is complicated by the diversity of helicopters, each with differing performance capabilities. Their differences become even more pronounced because of the numerous missions or various types of operations they perform. This results in different mission configurations which directly affect their operating weights and, ultimately, performance capabilities and the attendant real estate and airspace requirements. Helicopter performance thus becomes the dominant factor in heliport planning.

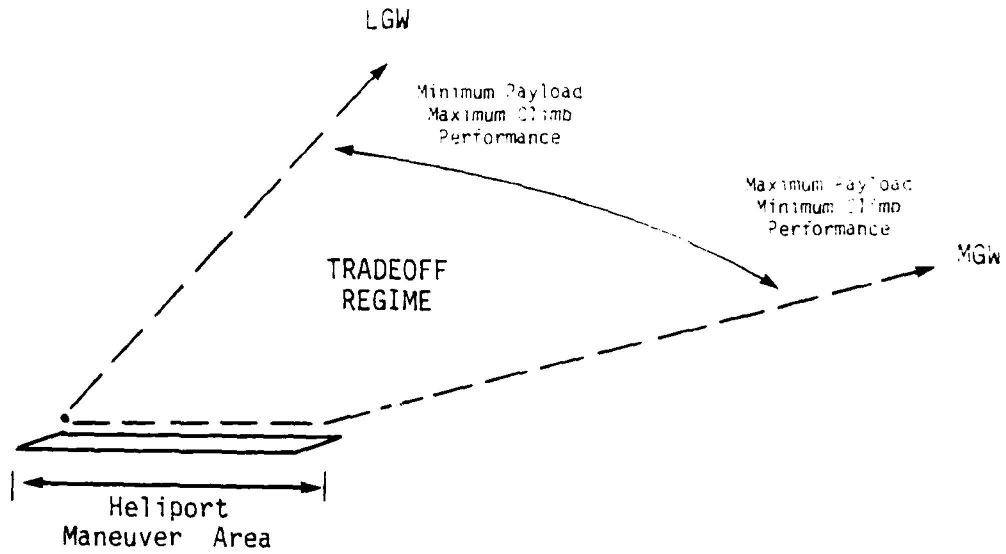


Figure 3A. <u>Heliport Tradeoff Regime</u>.

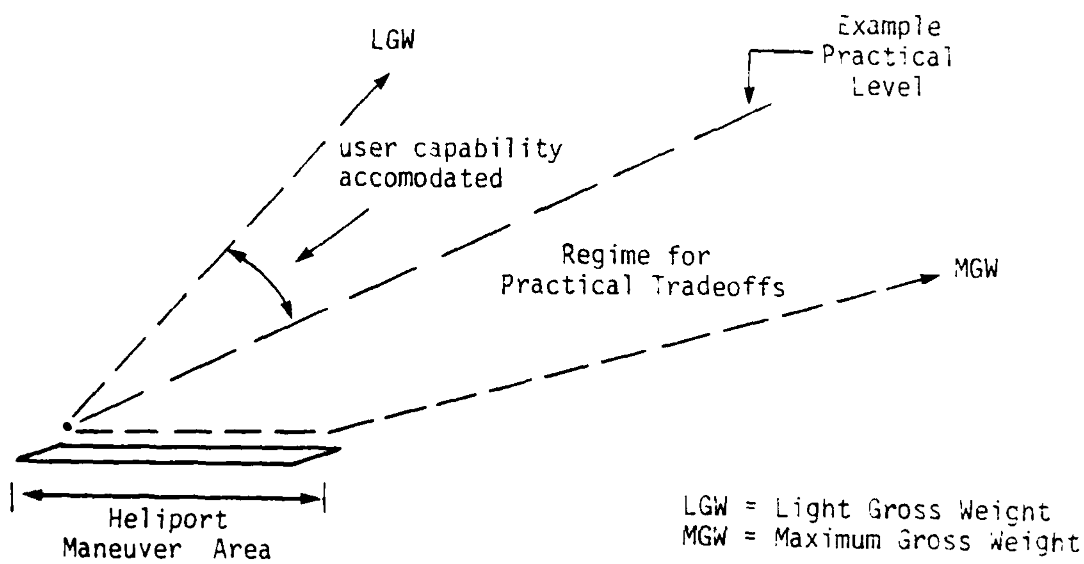


Figure 3B. <u>Practical Application of Tradeoffs</u>.

Figure 3. <u>Heliport Real Estate and Airspace Planning Decision</u>.

HELICOPTER PERFORMANCE CAPABILITIES

The earlier depicted flight profiles are useful to define and analyze the available performance capabilities and requirements for heliport operations. They further help define the performance characteristics or data which must be determined and studied. The real estate and airspace needed to accommodate the potential flight profiles is affected by the performance capabilities, or limitations, associated with the following flight regimes:

- hover
- acceleration
- deceleration
- climb
- descent

Detailed discussions of these flight regimes and their characteristics can be found in Reference 1 and also in an earlier work entitled Study of Helicopter Performance and Terminal Instrument Procedures (Reference 10).

Of these five flight regimes, the performance requirements of two dominate heliport planning considerations -- acceleration and climb. It has been previously reported (Reference 1) that deceleration and descent performance capabilities are assured within limiting acceleration and climb capabilities. That is, a helicopter which can safely depart along a prescribed flight path can safely use that same path on a reciprocal heading for approach and landing (no wind conditions both ways). Consequently, the following performance discussions focus on acceleration and climb performance. Hover capability enters indirectly through its influence on acceleration and climb. Details of the supporting analyses and theoretical rationale may be found in Appendix B.

A variety of helicopter design parameters which influence performance have been analyzed in order to devise a means for making generalized performance estimates. It was concluded that the most logical means of categorizing helicopters was to follow certification practice and distinguish between Normal Category helicopters -- helicopters of less than 6000 lbs. TOGW

(and certified in accordance with Reference 4), and Transport Category helicopters -- helicopters of more than 6000 lbs. TOGW (and certified in accordance with Reference 5). Distinctions between the certification requirements of the two references have tended to govern design tradeoffs to the extent that 6000 pounds now provides a natural division in characteristics. Further subdivision into engine type or number of engines is possible, but it dilutes the statistical base for evaluation of other parameters too much, thus complicating rather than aiding the process of generalization. Consequently, those design parameters which have proven to be of interest have been examined and further subdivided into three performance levels within each of these two helicopter categories -- Normal and Transport. Performance levels reflect the variance of these design parameters within a category by approximately defining a 95% confidence interval on the category mean. Performance levels are defined as follows:

Performance Level I -- Most (about 95%) modern helicopters in the category are able to perform at this level or better.

Performance Level II -- Approximately 50% of modern helicopters in the category can perform at this level or better, and 50% canot. Level II defines the mean within the category.

Performance Level III -- Few modern helicopters in the category can perform at this level or better.

Consequently, Levels I and III are approximate, not absolute, lower and upper bounds within the (Normal and Transport) category and Level II defines the expected mean value. For purposes of this report "modern" helicopters include those reflecting design philosophies of the 1960-1980 time frame.

These generalizations are based on single main rotor helicopters; the configuration which dominates current operational helicopters. The helicopters reviewed included only one tandem rotor helicopter and no coaxial,

synchropter, or side-by-side rotor configurations. The sample evaluated included few piston engine helicopters, so generalizations more reliably reflect characteristics of turbine powered helicopters. Single and multi-engine helicopters have been intermingled without distinction except in those discussions germane specifically to Transport Category A helicopters or to their unique operations.

Acceleration Performance

When only IGE hover is possible, when a Transport Category helicopter must accelerate to a climb speed above that prescribed by its limiting height-velocity (H-V) diagram, or when minimum IFR speed (or minimum IFR climb speed if applicable) must be attained before initiating climb, a level acceleration within a Heliport Maneuver Area is required. At altitudes below the HOGE ceiling, as may occur in either of the latter two conditions, acceleration rate is limited by practical rather than performance considerations. The acceleration rate attainable for departure from the hover is related to the amount of nose-down rotation made from the hover attitude. For passenger comfort this rotation should not be expected to normally exceed 10°. The resulting practical limit on acceleration rate is then about .18g for all helicopters that are operating below their HOGE ceiling. In the former case, when a helicopter is within its HIGE ceiling limitation, but is not able to hover OGE, .18g may not be safely attainable. A lesser, more tentative rotation is required to ensure that the desired height above the ground may be sustained. As discussed more fully in Appendix B, under these circumstances a 5° rotation may be about the maximum to expect which results in an acceleration rate of about .09g. Table 1 provides the distances needed to accelerate to airspeeds ranging from 10-70 Knots for acceleration rates between .04g and .20g.

The Heliport Maneuver Area size is dictated by these acceleration distances and the appropriate airspeeds for initiating climb. H-V diagrams for all Transport Category helicopters are defined in Reference 5 as limitations, which implies that minimum climb speeds are thereby prescribed. Resulting minimum climb speeds would be 30-40 Knots for multi-engine Transport Category helicopters and 50-60 Knots for single engine Transport

TABLE 1

HELIPORT MANEUVER AREA

ACCELERATION DISTANCES

Distances (in feet) Required to Accelerate to Various Airspeeds
for the Indicated Constant Acceleration Rates
and Corresponding Changes in Attitude

Acceleration Rate	Attitude Change	Airspeed at End of Acceleration (Knots) 10	20	30	35	40	45	50	55	60	65	70
.04g	2.3°	111	443	998	1358	1774	2245	2772	3354	3991	4684	5433
.06g	3.4°	74	296	665	905	1183	1497	1848	2236	2661	3123	3622
.08g	4.6°	55	222	499	679	887	1123	1386	1677	1996	2342	2716
.10g	5.7°	44	177	399	543	710	898	1109	1342	1597	1874	2173
.12g	6.8°	37	148	333	453	591	748	924	1118	1330	1561	1811
.14g	8.0°	32	127	285	388	507	641	792	958	1140	1338	1552
.16g	9.1°	28	111	249	340	443	561	693	838	998	1171	1358
.18g	10.2°	25	99	222	302	394	499	616	745	887	1041	1207
.20g	11.3°	22	89	200	272	355	449	554	671	798	937	1087

Category helicopters. The H-V diagram is not defined as a limitation in Normal Category helicopters by Reference 4. Instead, the H-V diagram defines "avoid" areas, which result in no implied requirements to observe a minimum climb speed. References 6 through 8 are silent on this topic.

Transport Category A helicopters demonstrate procedures which ensure safe handling of engine failure emergencies during the critical phases of takeoff and landing operations as part of their certification requirements. These procedures and the limiting WAT conditions and Heliport Maneuver Area lengths for which they apply are published in the RFM. Implicitly, Transport Category A helicopters should use either the Horizontal or Vertical Profiles shown in Figure 2; Transport Category B must use the Horizontal Profile; and Normal Category helicopters may use either the Horizontal or Direct Profile.

Inasmuch as all single engine helicopters above 6000 pounds TOGW fall into Transport Category B, this class of helicopters provides the dominant need for a significantly large Helicopter Maneuver Area under VFR conditions (50-60 Knots). However, minimum IFR airspeeds are typically 40-60 Knots; and, in one case, a minimum IFR climb speed of 70 Knots applies. Consequently, IFR heliports will need even larger Heliport Maneuver Areas (HMA), based on 70 Knots if all IFR certified helicopters are to be accommodated, until future design developments or modified certification criteria permit accelerating, climbing departures under IMC conditions.

As examples: (1) A VFR heliport is planned which will serve Transport Category B helicopters. All such helicopters which will use the heliport are expected to have minimum climb speeds of 50 Knots (as represented by their H-V diagrams). The altitude of the heliport and worst seasonal temperatures are not expected to limit performance, so Table 1 shows that .18g acceleration to 50 Knots requires an acceleration distance of 616 feet. This would define the minimum HMA for the stated circumstances. (2) An IFR heliport is planned at an altitude for which the worst seasonal temperatures preclude HOGE by a particular Normal Category helicopter which is expected to be a principal user of the heliport. This helicopter has a minimum IFR climb speed of 70 Knots. Using an acceleration rate of .09g to 70 Knots it is found, by interpolation, that 2445 feet are needed for the minimum HMA. If only 2000 feet are

available, this helicopter must be down loaded to a weight permitting HOGE which would thereby require an HMA of at least 1207 feet. (It should be realized that intermediate weights above that for HOGE may permit acceleration to 70 knots within the 2000 feet potentially available, but there is no requirement to define such capabilities in the RFM.)

One additional consideration applies to the HMA. Transport Category A helicopters have procedures defined for Horizontal Flight Profile departures. These procedures use the Balanced Heliport concept described in the introduction of this report in which the helicopter is accelerated in approximately level flight to a critical decision point at which the takeoff safety speed (TOSS) is reached. Failure of an engine before reaching TOSS results in an essentially level deceleration to a landing called a rejected takeoff. The rejected takeoff distance is the combined distance for acceleration and deceleration to a stop which may include a ground roll. Each Transport Category A helicopter for which such procedures have been approved has published in its RFM the rejected takeoff distances for all approved WAT combinations. Inasmuch as there are a limited number of such helicopters, and their procedures vary slightly, it is not possible to define a general rule for HMA to accommodate Transport Category A operations using Horizontal Flight Profile procedures. (The worst case for such procedures requires 2300 feet and the most favorable case noted requires 886 feet).

Climb Performance

Two modes of climb performance have been estimated -- Conventional Climb at airspeed for best rate of climb, V_y, and Direct (accelerating) Climb. In the Conventional Climb, power is assumed to be at the maximum continuous rating, V_y has already been attained, and the estimated climb performance is based on stabilized, sustainable conditions. In the Direct Climb, power is increased to takeoff rating as climb is initiated from hover (initially zero airspeed, zero rate of climb), and forward flight is concurrently initiated so that a constant climb gradient is maintained while accelerating and climbing simultaneously.

The Conventional Climb mode is typically used in conjunction with a Horizontal Profile departure, or the latter stages of Direct or Vertical Profile departures after clear of constraining obstacles. Climb gradients for Conventional Climb data should be used in conjunction with HMA dimensions to establish airspace requirements appropriate to heliports which require an HMA, i.e., heliports serving Transport Category B, IFR, or traffic likely to be operating above HOGE.

Direct Climbs are those initiated from hover for Direct Profile departures. A helicopter must be able to climb vertically to initiate such a climb. The climb gradients estimated herein for Direct Climb are based on a concurrent requirement for acceleration along a constant climb gradient. Steeper climbs are always possible for WAT conditions which permit this climb mode, but acceleration along the flight path may not be significant.

Data presented are based on a baseline helicopter in each of the Normal and Transport helicopter categories. A baseline helicopter weight was selected within each category which exhibited the least capability for the type of climb considered. Performance variations between weights within a category were small but distinguishable, hence the selection of one weight in each category to establish a baseline for that category.

Within each type of climb (Conventional and Direct), data are presented in tabular form for performance achieveable at each of the three performance levels -- Levels I, II and III. A further breakdown is made to show the effect of off-loading weight by showing climb gradients for each of three proportional weights -- 100%, 90% and 80% of the limiting TOGW. 80% of TOGW is an approximation of the minimum weight for a productive load. (Empty weight of turbine helicopters averages about 52% of TOGW; piston helicopters, 67%.) Data are presented for pressure altitudes ranging from sea level to 10,000 feet and for four temperature levels. The temperature levels are standard day conditions for each altitude and conditions of 10°C, 20°C, and 30°C hotter than standard day.

One remaining climb performance category is not estimated because of the limited population served; that is one engine inoperative (OEI) performance of Transport Category A helicopters. Generalizations are more readily made based on certification requirements. Reference 5 requires OEI demonstration of 100 feet per minute climb rate immediately after takeoff at the TOSS selected, and 150 feet per minute at V_y 1000 feet above the takeoff site. Typical TOSS range up to 52 Knots, which equates to a climb gradient of 53:1. V_y range up to about 80 Knots which equates to 54:1. For Horizontal Profile departures tailored to Transport Category A requirements, the 53:1 gradient should be protected from an HMA which would accommodate the rejected takeoff distance discussed under acceleration. For Direct Profile departures, the 53:1 gradient should be protected from a point 35 feet above the departure edge of the heliport (HMA). (35 feet is the minimum altitude permitted in attaining TOSS after the critical decision point in a Direct Profile departure).

Climb Gradients

Data developed herein are presented in part as figures for discussion of pertinent characteristics. Following the figures are comprehensive tables which present climb gradients based on the full range of all WAT conditions and performance levels previously cited.

Figures 4A and 4B provide a comparison of the impact of performance levels on the variation of climb gradient capability with changes in pressure altitude. Figure 4A shows Conventional Climb data. First, note that for each variety of climb, performance level has a major impact on capability. (Subsequent figures will show that weight and temperature changes have less significant effects within the ranges of data presented.) Figures 4A and 4B are both presented for standard day temperatures (corresponding to applicable altitudes) at 100% of the limiting TOGW. It should also be noted that climb gradient becomes less steep with increasing altitude for both types of climb. However, the accelerating Direct Climb is much more sensitive to both changes in altitude and differences between performance levels. Conventional Climbs cannot achieve the high climb angles possible under some circumstances for the accelerating Direct Climb since Conventional Climbs are conducted at Vy, approximately the speed for minimum power in forward flight. Direct Climbs,

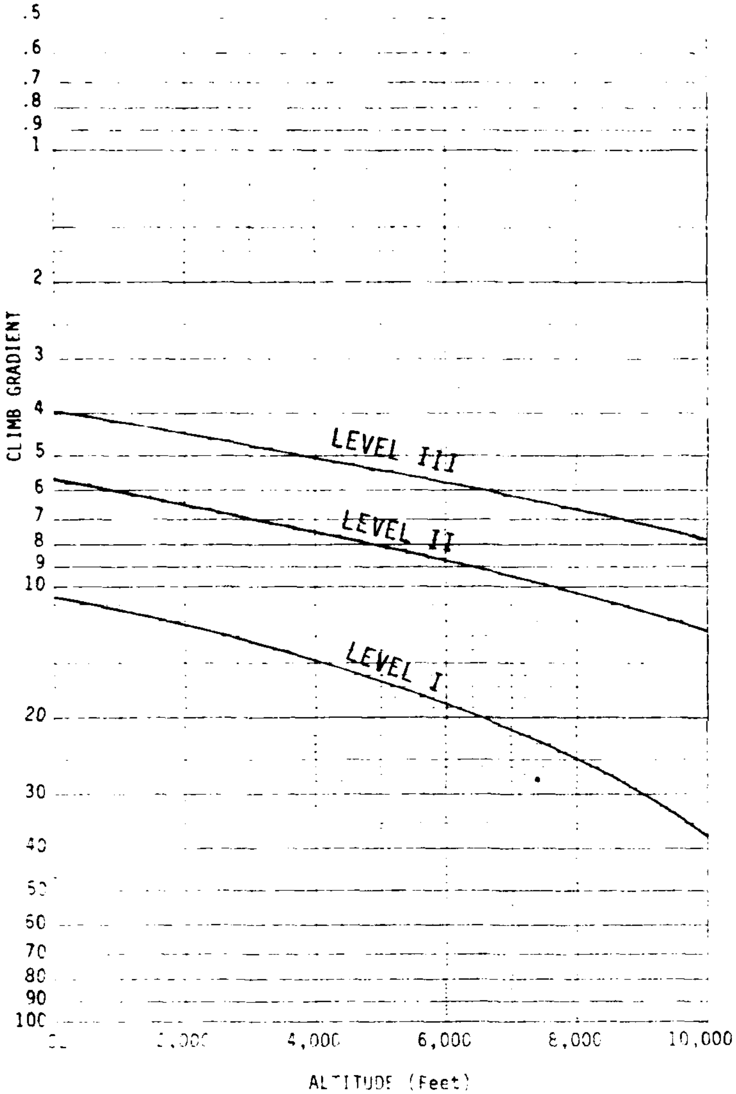


Figure 4A. Conventional Climb

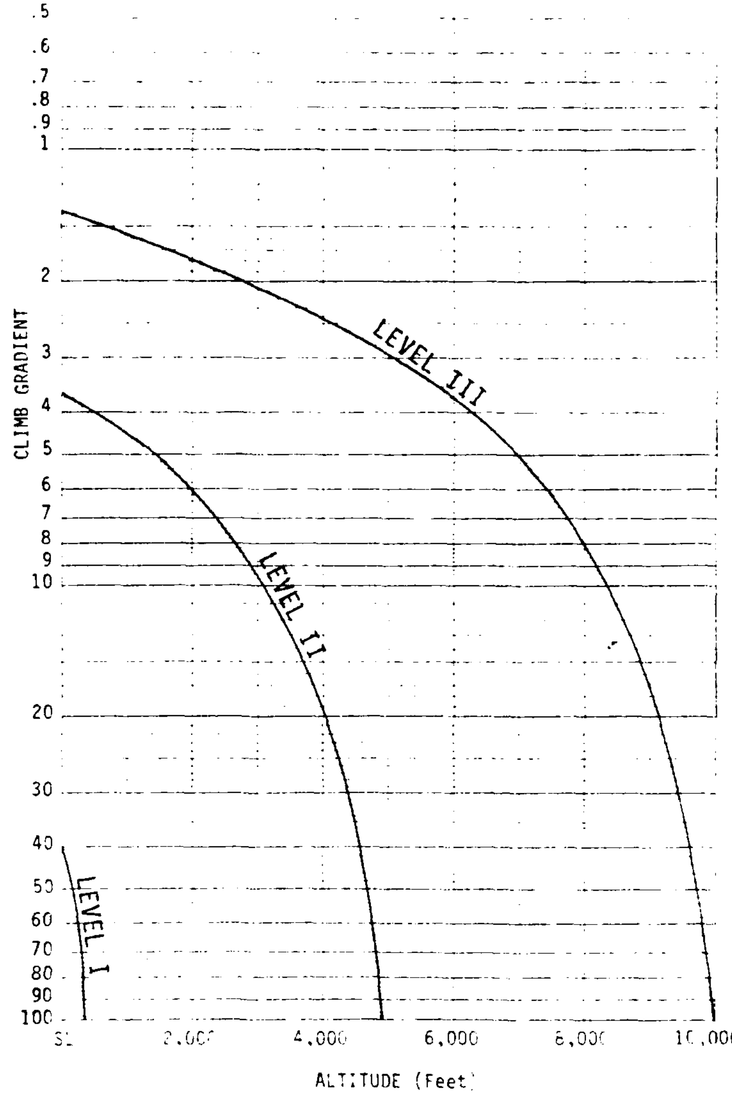


Figure 4B. Direct Climb

Figure 4. Comparison of Conventional and Direct Climb Capabilities for Normal Category Helicopters at Three Performance Levels

as defined herein, sustains a constant climb angle which implies that the forward component of velocity must be limited to something less than Vy. It should also be noted that Level I helicopters cannot achieve Direct Climb gradients as steep as their Conventional Climb gradients for the conditions shown. As altitude increases, the same becomes true of Levels II and III successively.

Figures 5A and 5B show corresponding data for Transport Category helicopters. General trends and relationships shown by these figures are similar to those discussed above for Normal Category helicopters. Transport Category helicopters do exhibit an overall higher level of performance than Normal Category helicopters with less apparent variations between levels.

Figures 6A and 6B focus on Normal Category helicopters at Performance Level II as an example of comparisons which could also have been made between other performance levels or employing Transport Category helicopters. The purpose of Figures 6A and 6B is to illustrate the impacts of temperature and gross weight and to demonstrate that their combined effects define three flight regimes (in terms of altitude and climb gradient). One of these flight regimes can be achieved for any combination of temperature and gross weight illustrated; one flight regime is not achievable at all; and the flight regime intermediate to these two requires some tradeoff of gross weight to achieve climb capability for particular combinations of altitude and temperature.

In Figure 6A, four solid lines show the limiting Conventional Climb capability at temperatures of 30° above, 20° above, 10° above, and at standard day temperatures corresponding to the plotted altitude. Each of these solid lines represents 100% of TOGW. Two dashed lines above show the influence of reducing weight, the lower line representing 90% of the limiting TOGW at the standard temperatures of the adjacent solid line. The second dashed line represents 80% of TOGW for the same standard day conditions. Analagous reductions can readily be imagined for each of the hotter conditions shown, but their presentation on the graph would conflict with the lines depicted. Figure 6B shows similar information for the accelerating Direct Climb; however, no line is present for temperatures of 30° above standard. Level II Normal Category helicopters do not have Direct Climb capability at 100% of TOGW at such temperatures.

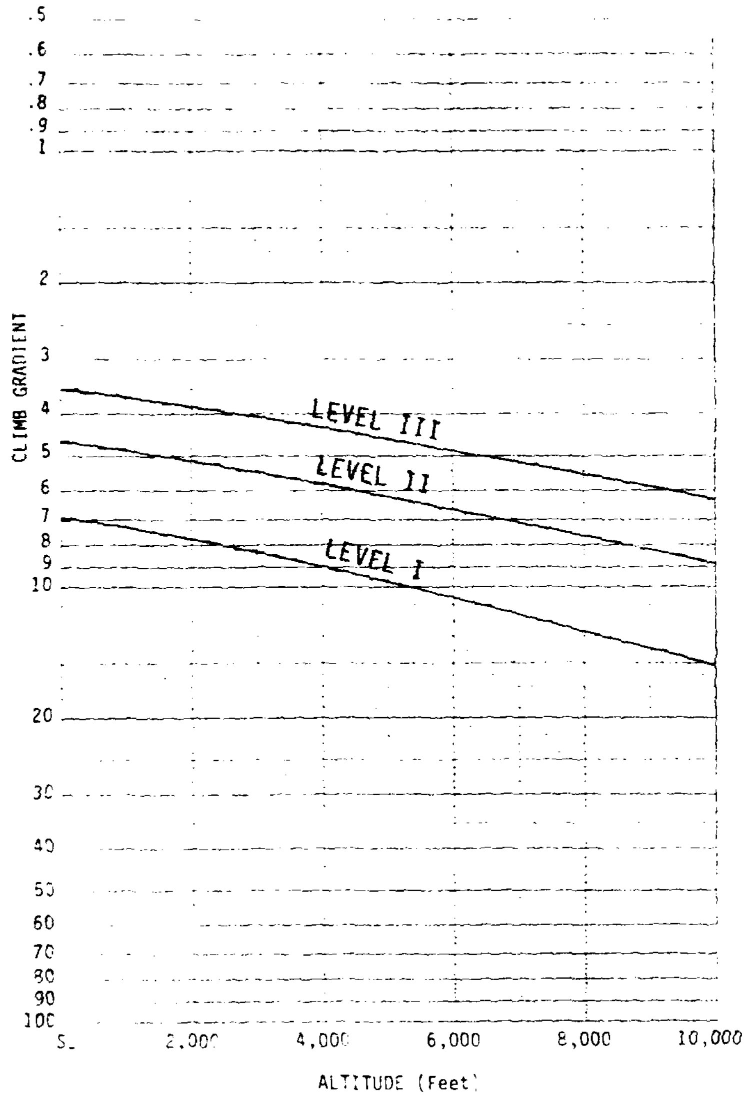


Figure 5A. Conventional Climb

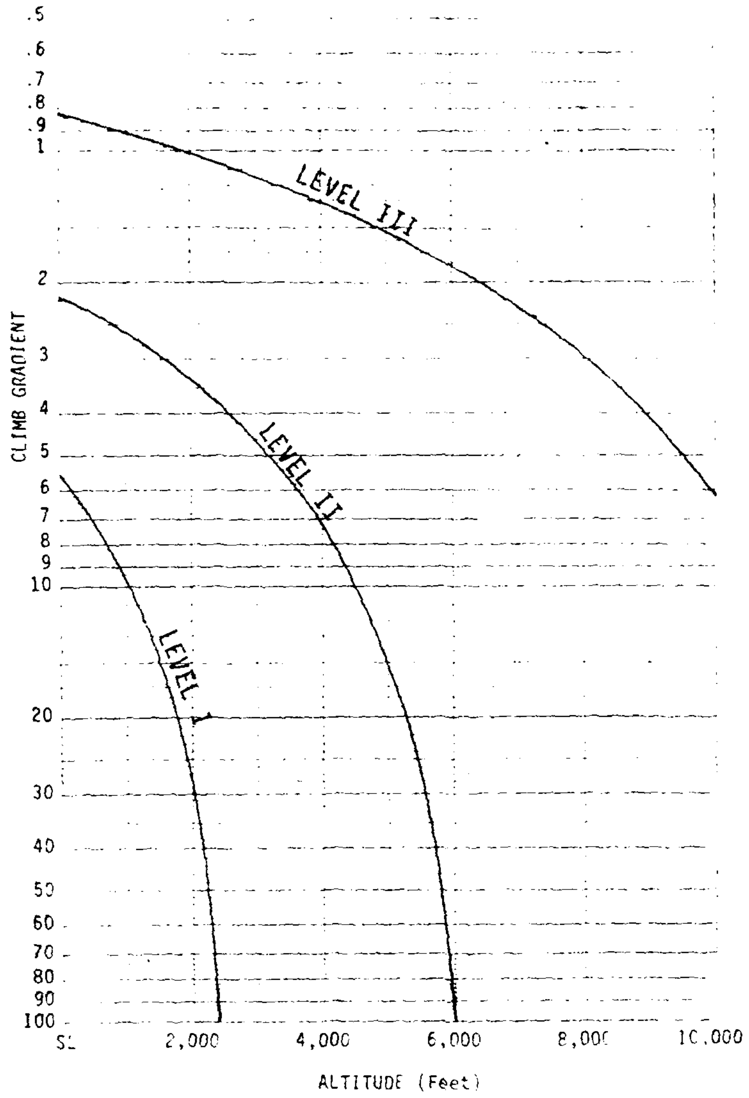


Figure 5B. Direct Climb

Figure 5. Comparison of Conventional and Direct Climb Capabilities for Transport Category Helicopters at Three Performance Levels

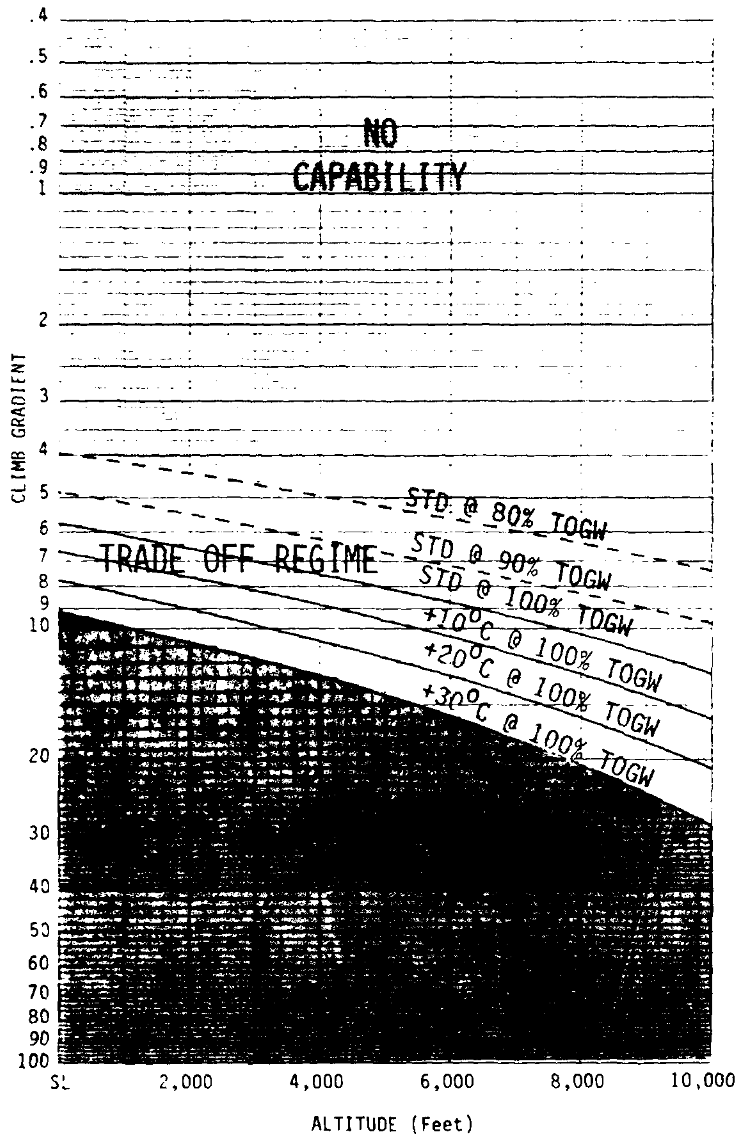


Figure 6A. Conventional Climb

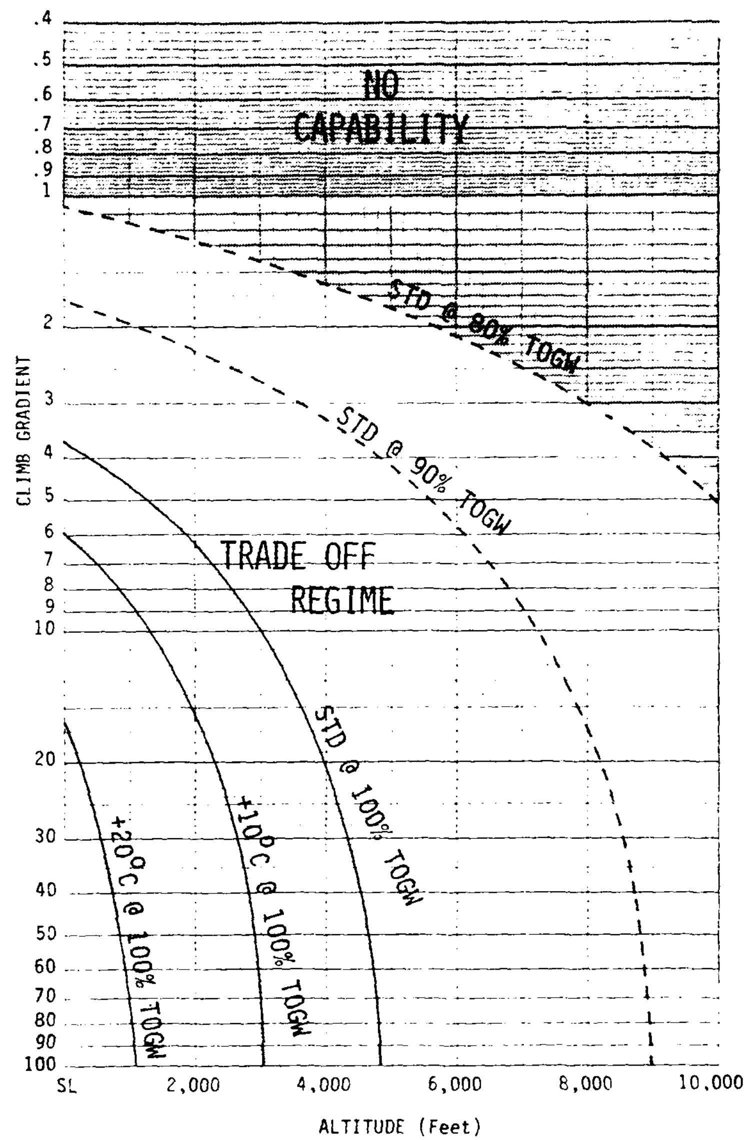


Figure 6B. Direct Climb

Figure 6. Conventional and Direct Climb for Differing Conditions of Weight, Altitude and Temperature, Normal Category Helicopters of Level II

The region included between these performance lines is shown as a tradeoff regime while the region below the lowest line is indicated to have unlimited climb capability and the region above the highest has no capability. Each of the four solid lines is the upper limit of the unlimited capability region for its applicable temperatures. Likewise, the dashed lines would project downward to a corresponding lower level at higher temperatures. The upper limit of the tradeoff regime is not sharply defined because weight tradeoffs below 80% are possible, but with rapidly diminishing productive utility.

Figures 7A, 7B and 7C show Conventional Climb capability for Performance Levels I, II and III respectively. Format is the same as in Figure 6A . The same principles previously discussed are equally valid for both Levels I and III, and were more fully dicussed for Level II.

Figures 8A, B and C provide Direct Climb data for Levels I, II and III respectively. Direct Climb capability is highly variable and may require reduction in takeoff weight, even at low altitudes, to attain the capability to climb along a useful gradient.

Tables 2 through 17 present the full scope of these data for use in planning heliports. As an example of their utility, let us assume we wish to operate a heliport which will be located 2000 feet above sea level. The worst weather conditions routinely expected may raise the pressure altitude to 2500 feet (during passage of a summertime low pressure system) with a concurrent temperature 20°C warmer than standard day. We are concerned about Normal Category helicopter operations with no HMA. Table 12 shows that Level II helicopters have a negligible Direct Climb capability at 100% of TOGW, but can achieve 5.32:1 at 90% of TOGW. Level I helicopters would be required to download to 80% of TOGW to better 8:1 and Level III helicopters could achieve 5.05:1 at full TOGW. Such a heliport would have general utility, but some helicopters (probably about half of potential types) would need to trade some potential payload to achieve satisfactory performance levels. To extend this example, if we had been more concerned about high temperature as the dominant weather extreme, the worst conditions would be 2000 feet altitude but 30°C warmer than standard day. Using Table 13, we find that: a Level I Normal

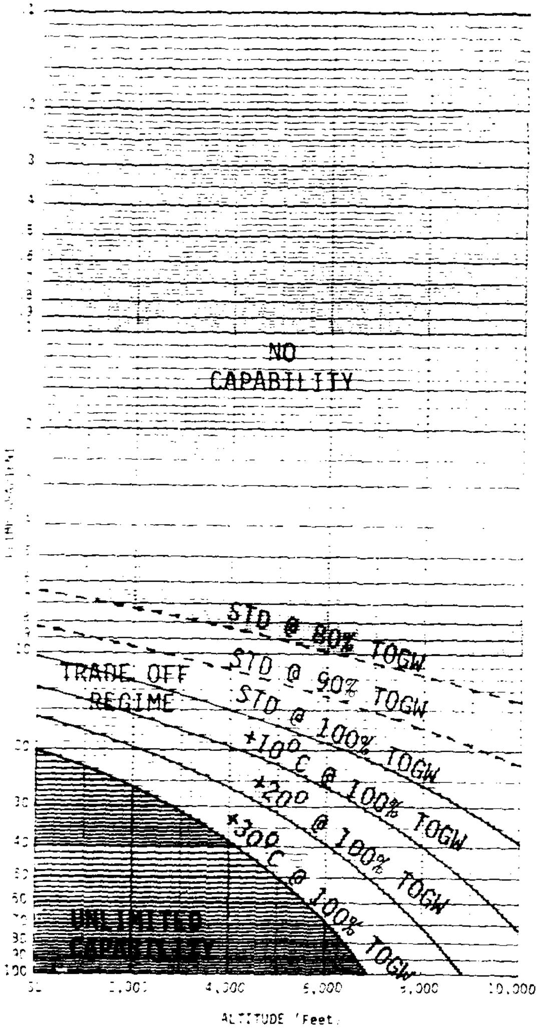


Figure 7A. Performance Level I

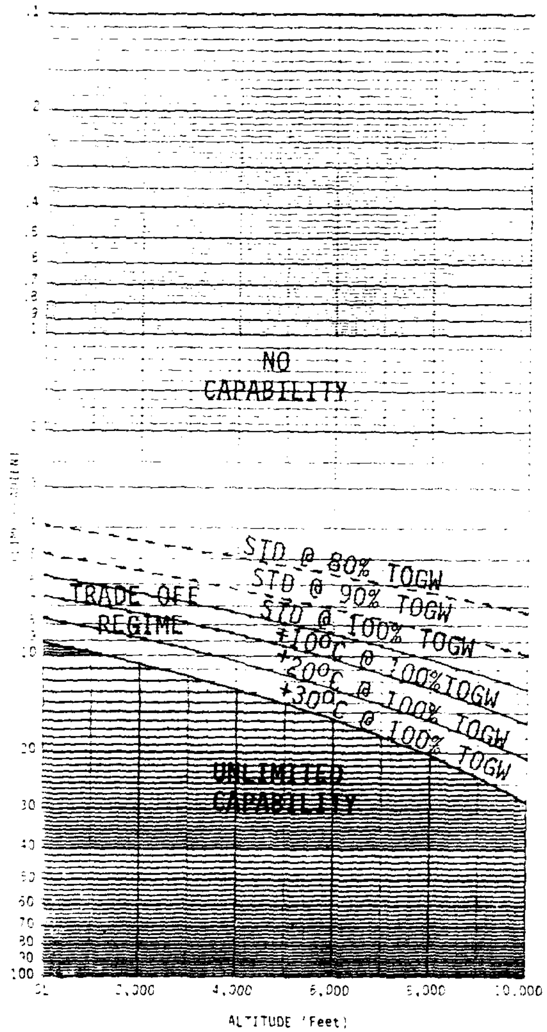


Figure 7B. Performance Level II

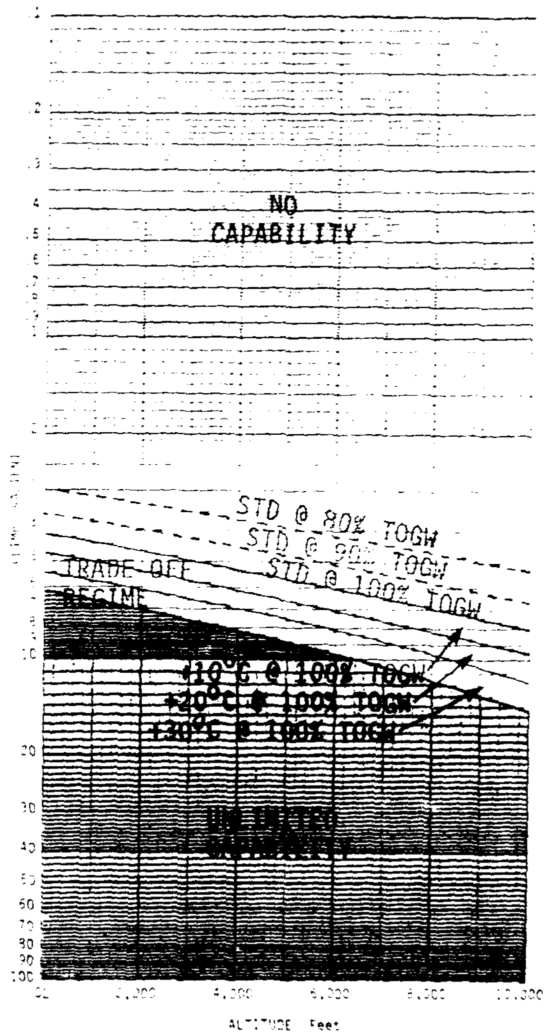


Figure 7C. Performance Level III

Figure 7. Variations in Conventional Climb for Three Performance Levels (Normal Category Helicopters) with Differing Weight, Altitude and Temperature

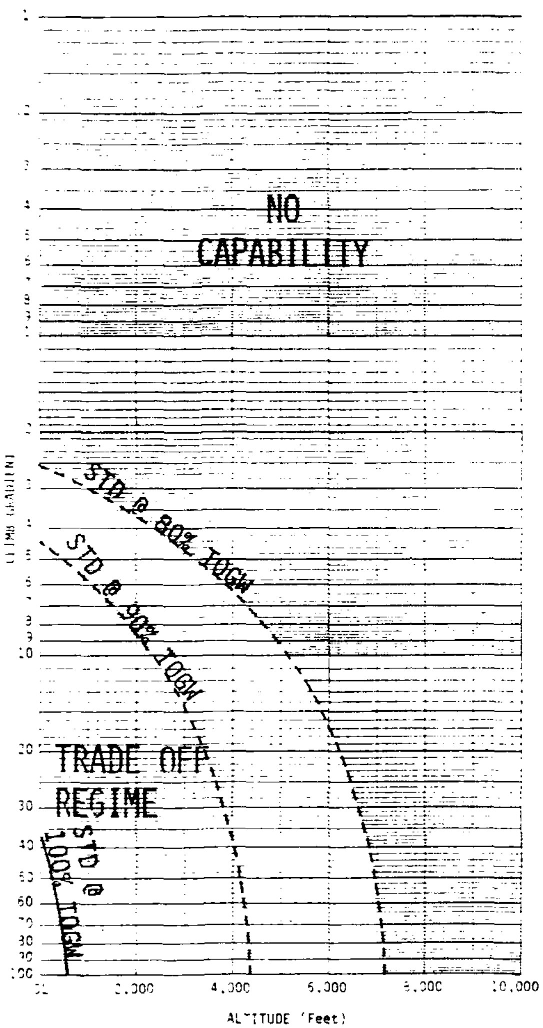


Figure 8A. Performance Level I

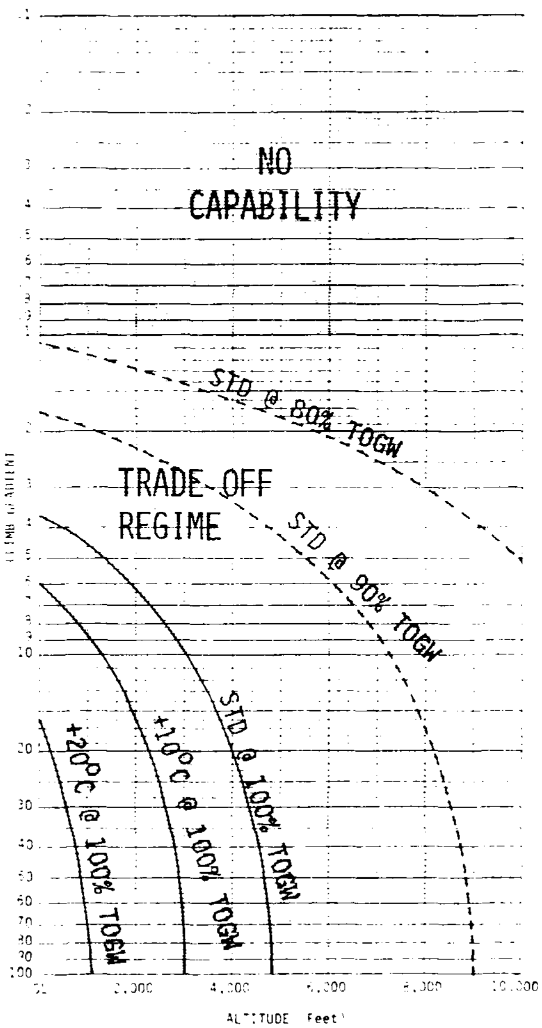


Figure 8B. Performance Level II

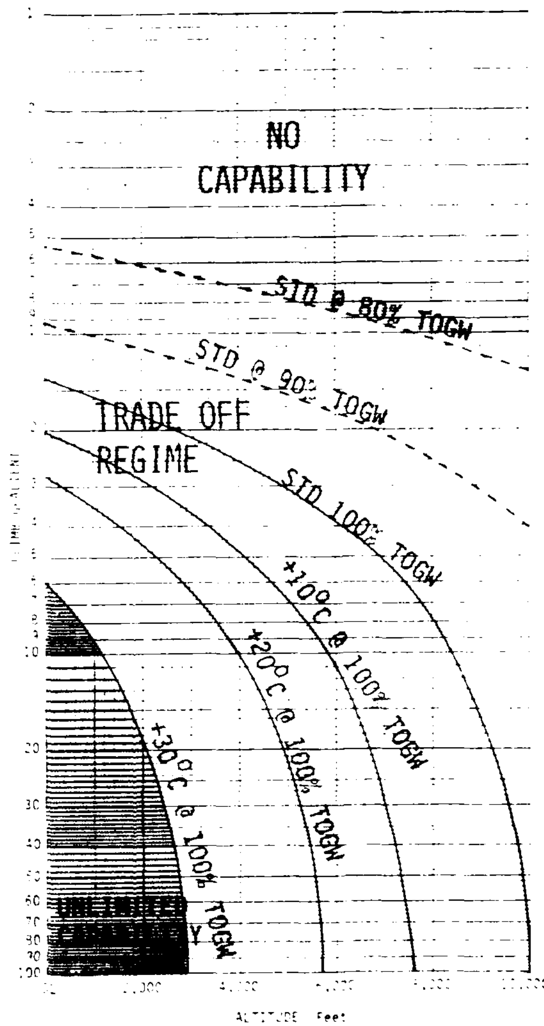


Figure 8C. Performance Level III

Figure 8. Variations in Direct Climb for Three Performance Levels (Normal Category Helicopters) with Differing Weight, Altitude and Temperature

TABLE 2

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES

NORMAL CATEGORY HELICOPTERS

		PERFORMANCE LEVELS								
PRESSURE		I			II			III		
ALTITUDE	TEMP	Percent Max. TOGW			Percent Max. TOGW			Percent Max. TOGW		
(feet)	(°C)	100%	90%	80%	100%	90%	80%	100%	90%	80%
S.L.	+15	10.05	8.08	6.28	5.62	4.79	3.93	3.98	3.45	2.90
500	+14	10.49	8.38	6.49	5.80	4.94	4.05	4.10	3.56	2.98
1,000	+13	10.97	8.71	6.70	6.00	5.09	4.16	4.22	3.67	3.06
1,500	+12	11.48	9.05	6.93	6.21	5.26	4.28	4.35	3.78	3.14
2,000	+11	12.03	9.42	7.16	6.43	5.42	4.41	4.49	3.89	3.25
2,500	+10	12.63	9.81	7.41	6.65	5.60	4.54	4.63	4.00	3.32
3,000	+ 9	13.28	10.23	7.67	6.90	5.79	4.67	4.78	4.12	3.42
3,500	+ 8	13.98	10.67	7.95	7.15	5.98	4.82	4.93	4.25	3.51
4,000	+ 7	14.76	11.15	8.24	7.43	6.18	4.96	5.10	4.38	3.62
4,500	+ 6	15.61	11.67	8.55	7.71	6.40	5.12	5.27	4.51	3.72
5,000	+ 5	16.55	12.23	8.88	8.02	6.62	5.28	5.44	4.66	3.85
6,000	+ 3	18.76	13.48	9.60	8.69	7.11	5.62	5.83	4.96	4.06
7,000	+ 1	21.54	14.97	10.41	9.45	7.66	6.00	6.25	5.29	4.31
8,000	- 1	25.16	16.76	11.34	10.33	8.27	6.41	6.72	5.65	4.58
9,000	- 3	30.04	18.96	12.41	11.35	8.96	6.87	7.25	6.05	4.87
10,000	- 5	36.99	21.71	13.67	12.54	9.75	7.38	7.84	6.49	5.19

TABLE 3

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES +10°C

NORMAL CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
S.L.	+25	12.36	9.64	7.30	6.55	5.52	4.48	4.57	3.95	3.28
500	+24	12.98	10.04	7.56	6.79	5.70	4.61	4.71	4.07	3.37
1,000	+23	13.65	10.46	7.82	7.03	5.89	4.75	4.86	4.19	3.47
1,500	+22	14.38	10.92	8.10	7.29	6.09	4.89	5.02	4.32	3.57
2,000	+21	15.18	11.41	8.40	7.57	6.29	5.04	5.18	4.45	3.67
2,500	+20	16.06	11.94	8.71	7.86	6.51	5.20	5.35	4.58	3.77
3,000	+19	17.04	12.51	9.04	8.17	6.74	5.36	5.53	4.73	3.88
3,500	+18	18.12	13.12	9.40	8.50	6.98	5.53	5.72	4.87	4.00
4,000	+17	19.32	13.79	9.77	8.85	7.23	5.70	5.92	5.03	4.11
4,500	+16	20.68	14.52	10.17	9.22	7.50	5.89	6.12	5.19	4.23
5,000	+15	22.21	15.31	10.59	9.62	7.78	6.08	6.34	5.36	4.36
6,000	+13	25.98	17.15	11.54	10.51	8.40	6.50	6.82	5.72	4.63
7,000	+11	31.08	19.40	12.62	11.54	9.09	6.95	7.35	6.13	4.92
8,000	+ 9	38.41	22.23	13.89	12.76	9.89	7.46	7.94	6.57	5.24
9,000	+ 7	49.73	25.87	15.38	14.19	10.80	8.03	8.62	7.06	5.59
10,000	+ 5	69.65	30.77	17.16	15.94	11.86	8.67	9.39	7.62	5.97

TABLE 4

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES +20°C

NORMAL CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
S.L.	+35	15.37	11.52	8.47	7.63	6.34	5.07	5.22	4.48	3.69
500	+34	16.26	12.05	8.78	7.92	6.55	5.23	5.39	4.61	3.80
1,000	+33	17.24	12.62	9.11	8.23	6.78	5.39	5.57	4.75	3.90
1,500	+32	18.32	13.24	9.46	8.56	7.02	5.56	5.75	4.90	4.02
2,000	+31	19.53	13.90	9.83	8.91	7.27	5.73	5.95	5.05	4.13
2,500	+30	20.89	14.63	10.23	9.28	7.54	5.91	6.16	5.22	4.25
3,000	+29	22.43	15.43	10.65	9.68	7.82	6.11	6.37	5.38	4.38
3,500	+28	24.19	16.29	11.10	10.10	8.12	6.31	6.60	5.56	4.51
4,000	+27	26.21	17.26	11.59	10.56	8.43	6.52	6.84	5.74	4.64
4,500	+26	28.55	18.31	12.11	11.05	8.77	6.74	7.10	5.94	4.79
5,000	+25	31.32	19.49	12.67	11.58	9.12	6.97	7.37	6.14	4.95
6,000	+23	38.62	22.30	13.92	12.79	9.91	7.48	7.96	6.58	5.25
7,000	+21	49.87	25.91	15.39	14.21	10.81	8.04	8.62	7.07	5.59
8,000	+19	69.58	30.75	17.16	15.93	11.86	8.67	9.39	7.61	5.97
9,000	+17	112.51	37.51	19.29	18.04	13.08	9.37	10.26	8.22	6.38
10,000	+15	280.71	47.69	21.93	20.70	14.53	10.17	11.28	8.92	6.84

TABLE 5

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES +30°C

NORMAL CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
S.L.	+45	19.43	13.85	9.80	8.88	7.25	5.72	5.93	5.04	4.12
500	+44	20.76	14.56	10.19	9.25	7.51	5.90	6.14	5.26	4.24
1,000	+43	22.27	15.34	10.61	9.64	7.79	6.09	6.35	5.37	4.37
1,500	+42	23.97	16.19	11.05	10.05	8.08	6.28	6.57	5.54	4.49
2,000	+41	25.92	17.12	11.52	10.50	8.39	6.49	6.81	5.72	4.63
2,500	+40	28.18	18.15	12.03	10.98	8.72	6.71	7.06	5.91	4.76
3,000	+39	30.84	19.30	12.57	11.50	9.07	6.94	7.32	6.11	4.91
3,500	+38	33.99	20.57	13.16	12.06	9.44	7.17	7.60	6.32	5.06
4,000	+37	37.81	22.01	13.80	12.67	9.83	7.43	7.90	6.54	5.22
4,500	+36	42.49	23.63	14.48	13.32	10.26	7.69	8.21	6.77	5.38
5,000	+35	48.40	25.48	15.23	14.05	10.71	7.97	8.55	7.01	5.55
6,000	+33	66.48	30.09	16.93	15.71	11.72	8.59	9.29	7.54	5.92
7,000	+31	104.09	36.46	18.98	17.73	12.90	9.27	10.14	8.14	6.32
8,000	+29	231.54	45.92	21.52	20.27	14.30	10.05	11.12	8.81	6.77
9,000	+27	NC	61.25	24.70	23.52	15.97	10.94	12.26	9.57	7.26
10,000	+25	NC	90.65	28.84	27.85	18.00	11.96	13.63	10.45	7.81

NC = No Climb Capability

TABLE 6

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	90%	80%	II Percent Max. TOGW 100%	90%	80%	III Percent Max. TOGW 100%	90%	80%
S.L.	+15	6.78	5.81	4.80	4.52	3.97	3.35	3.44	3.05	2.59
500	+14	7.00	5.99	4.93	4.65	4.08	3.44	3.53	3.13	2.66
1,000	+13	7.24	6.17	5.07	4.79	4.19	3.53	3.63	3.21	2.73
1,500	+12	7.48	6.36	5.21	4.93	4.31	3.62	3.73	3.30	2.80
2,000	+11	7.74	6.56	5.36	5.07	4.43	3.72	3.84	3.39	2.88
2,500	+10	8.01	6.77	5.52	5.23	4.55	3.82	3.95	3.48	2.95
3,000	+ 9	8.29	6.99	5.68	5.39	4.69	3.92	4.06	3.58	3.03
3,500	+ 8	8.60	7.22	5.85	5.55	4.82	4.03	4.18	3.68	3.11
4,000	+ 7	8.92	7.46	6.02	5.73	4.96	4.14	4.30	3.78	3.20
4,500	+ 6	9.25	7.71	6.20	5.91	5.11	4.26	4.42	3.89	3.28
5,000	+ 5	9.61	7.98	6.39	6.10	5.26	4.38	4.55	4.00	3.37
6,000	+ 3	10.40	8.56	6.80	6.51	5.59	4.63	4.83	4.23	3.56
7,000	+ 1	11.29	9.20	7.25	6.95	5.95	4.90	5.13	4.48	3.76
8,000	- 1	12.31	9.92	7.74	7.45	6.34	5.19	5.46	4.75	3.97
9,000	- 3	13.49	10.73	8.28	8.00	6.76	5.51	5.82	5.04	4.20
10,000	- 5	14.87	11.66	8.88	8.61	7.23	5.86	6.22	5.36	4.45

TABLE 7

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES +10°C

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	90%	80%	II Percent Max. TOGW 100%	90%	80%	III Percent Max. TOGW 100%	90%	80%
S.L.	+25	7.89	6.68	5.45	5.16	4.50	3.78	3.90	3.44	2.92
500	+24	8.17	6.89	5.61	5.31	4.63	3.88	4.01	3.53	3.00
1,000	+23	8.46	7.11	5.77	5.48	4.76	3.98	4.12	3.63	3.08
1,500	+22	8.76	7.34	5.94	5.64	4.90	4.09	4.24	3.73	3.16
2,000	+21	9.08	7.59	6.11	5.82	5.04	4.20	4.36	3.83	3.24
2,500	+20	9.43	7.84	6.30	6.00	5.19	4.32	4.49	3.94	3.33
3,000	+19	9.79	8.11	6.49	6.19	5.34	4.44	4.62	4.05	3.42
3,500	+18	10.17	8.39	6.69	6.39	5.50	4.56	4.75	4.16	3.51
4,000	+17	10.58	8.69	6.90	6.60	5.67	4.69	4.90	4.28	3.60
4,500	+16	11.02	9.01	7.12	6.82	5.84	4.82	5.05	4.40	3.70
5,000	+15	11.49	9.34	7.35	7.05	6.02	4.96	5.20	4.53	3.80
6,000	+13	12.52	10.07	7.84	7.55	6.41	5.25	5.53	4.80	4.02
7,000	+11	13.72	10.89	8.38	8.10	6.84	5.57	5.89	5.10	4.25
8,000	+ 9	15.12	11.82	8.98	8.72	7.31	5.92	6.28	5.41	4.49
9,000	+ 7	16.77	12.88	9.65	9.41	7.83	6.29	6.72	5.76	4.76
10,000	+ 5	18.76	14.11	10.40	10.20	8.41	6.70	7.20	6.14	5.05

TABLE 8

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES +20°C

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
S.L.	+35	9.16	7.64	6.15	5.86	5.07	4.23	4.39	3.86	3.26
500	+34	9.50	7.90	6.34	6.04	5.22	4.34	4.51	3.96	3.34
1,000	+33	9.86	8.17	6.53	6.23	5.37	4.46	4.64	4.07	3.43
1,500	+32	10.25	8.45	6.73	6.43	5.53	4.58	4.78	4.18	3.52
2,000	+31	10.65	8.74	6.93	6.64	5.70	4.71	4.92	4.30	3.62
2,500	+30	11.09	9.06	7.15	6.85	5.87	4.84	5.07	4.42	3.72
3,000	+29	11.55	9.39	7.38	7.08	6.05	4.98	5.22	4.55	3.82
3,500	+28	12.05	9.74	7.61	7.32	6.24	5.12	5.38	4.68	3.92
4,000	+27	12.58	10.11	7.86	7.58	6.44	5.27	5.55	4.82	4.03
4,500	+26	13.15	10.50	8.13	7.84	6.64	5.42	5.72	4.96	4.14
5,000	+25	13.77	10.92	8.40	8.13	6.86	5.58	5.90	5.11	4.26
6,000	+23	15.16	11.84	9.00	8.74	7.33	5.92	6.29	5.42	4.50
7,000	+21	16.79	12.89	9.66	9.42	7.84	6.29	6.72	5.76	4.76
8,000	+19	18.76	14.11	10.40	10.19	8.41	6.70	7.20	6.14	5.04
9,000	+17	21.14	15.52	11.23	11.07	9.04	7.14	7.72	6.55	5.35
10,000	+15	24.12	17.19	12.17	12.08	9.76	7.63	8.30	7.00	5.68

TABLE 9

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES +30°C

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
S.L.	+45	10.62	8.72	6.92	6.62	5.68	4.70	4.91	4.29	3.61
500	+44	11.05	9.03	7.13	6.83	5.85	4.83	5.05	4.41	3.71
1,000	+43	11.50	9.35	7.35	7.06	6.03	4.96	5.21	4.54	3.81
1,500	+42	11.99	9.70	7.59	7.30	6.22	5.10	5.36	4.67	3.91
2,000	+41	12.51	10.06	7.83	7.54	6.41	5.25	5.53	4.80	4.01
2,500	+40	13.07	10.44	8.09	7.80	6.61	5.40	5.70	4.94	4.12
3,000	+39	13.67	10.85	8.36	8.08	6.82	5.56	5.87	5.08	4.24
3,500	+38	14.31	11.29	8.64	8.37	7.05	5.72	6.06	5.23	4.35
4,000	+37	15.02	11.75	8.94	8.68	7.28	5.89	6.26	5.39	4.48
4,500	+36	15.78	12.24	9.25	9.00	7.52	6.07	6.46	5.56	4.60
5,000	+35	16.60	12.77	9.58	9.34	7.78	6.25	6.67	5.73	4.73
6,000	+33	18.50	13.95	10.30	10.10	8.34	6.65	7.14	6.09	5.01
7,000	+31	20.80	15.32	11.11	10.95	8.96	7.08	7.65	6.49	5.31
8,000	+29	23.65	16.93	12.02	11.92	9.65	7.56	8.21	6.93	5.63
9,000	+27	27.26	18.84	13.06	13.05	10.43	8.08	8.85	7.41	5.98
10,000	+25	32.00	21.15	14.25	14.35	11.31	8.66	9.56	7.94	6.37

TABLE 10

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES

NORMAL CATEGORY HELICOPTERS

		PERFORMANCE LEVELS								
PRESSURE		I			II			III		
ALTITUDE	TEMP	Percent Max. TOGW			Percent Max. TOGW			Percent Max. TOGW		
(feet)	(°C)	100%	90%	80%	100%	90%	80%	100%	90%	80%
HOGE Limit (ft.)		600	4,500	7,200	5,000	9,200	13,400	10,200	13,900	19,600
S.L.	+15	35.76	4.24	2.51	3.55	1.70	1.03	1.40	0.92	0.53
500	+14	234.23	4.81	2.73	3.98	1.82	1.08	1.48	0.96	0.55
1,000	+13	NC	5.55	2.98	4.52	1.95	1.14	1.58	1.01	0.57
1,500	+12	NC	6.54	3.27	5.21	2.09	1.20	1.68	1.06	0.59
2,000	+11	NC	7.92	3.61	6.14	2.26	1.26	1.80	1.11	0.61
2,500	+10	NC	9.99	4.04	7.44	2.45	1.33	1.94	1.17	0.64
3,000	+ 9	NC	13.42	4.56	9.38	2.68	1.41	2.09	1.24	0.66
3,500	+ 8	NC	20.29	5.22	12.62	2.94	1.49	2.27	1.31	0.69
4,000	+ 7	NC	41.01	6.10	19.15	3.25	1.59	2.48	1.39	0.72
4,500	+ 6	NC	NC	7.30	38.52	3.63	1.69	2.72	1.48	0.75
5,000	+ 5	NC	NC	9.05	NC	4.11	1.81	3.01	1.58	0.79
6,000	+ 3	NC	NC	16.93	NC	5.50	2.10	3.80	1.81	0.86
7,000	+ 1	NC	NC	105.11	NC	8.16	2.47	5.08	2.12	0.95
8,000	- 1	NC	NC	NC	NC	15.28	2.99	7.53	2.52	1.05
9,000	- 3	NC	NC	NC	NC	97.06	3.74	14.10	3.10	1.17
10,000	- 5	NC	NC	NC	NC	NC	4.94	86.91	3.98	1.32

NC = No Climb Capability

TABLE 11

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES +10°C

NORMAL CATEGORY HELICOPTERS

		PERFORMANCE LEVELS								
PRESSURE		I			II			III		
ALTITUDE	TEMP	Percent Max. TOGW			Percent Max. TOGW			Percent Max. TOGW		
(feet)	(°C)	100%	90%	80%	100%	90%	80%	100%	90%	80%
HOGE Limit (ft.)		-600	3,500	6,800	3,200	7,800	11,900	7,600	12,100	17,000
S.L.	+25	NC	5.57	2.53	5.74	2.10	1.22	2.04	1.11	0.68
500	+24	NC	6.56	2.75	6.85	2.26	1.28	2.20	1.17	0.70
1,000	+23	NC	7.95	3.00	8.45	2.45	1.35	2.39	1.24	0.73
1,500	+22	NC	10.04	3.30	10.95	2.68	1.43	2.61	1.31	0.76
2,000	+21	NC	13.50	3.66	15.44	2.94	1.52	2.87	1.38	0.80
2,500	+20	NC	20.48	4.09	25.90	3.24	1.62	3.18	1.47	0.83
3,000	+19	NC	42.50	4.63	78.04	3.62	1.72	3.56	1.56	0.87
3,500	+18	NC	NC	5.33	NC	4.09	1.84	4.02	1.67	0.91
4,000	+17	NC	NC	6.25	NC	4.66	1.98	4.63	1.79	0.95
4,500	+16	NC	NC	7.51	NC	5.44	2.13	5.41	1.93	1.00
5,000	+15	NC	NC	9.39	NC	6.50	2.31	6.50	2.08	1.05
6,000	+13	NC	NC	18.31	NC	10.41	2.76	10.72	2.47	1.17
7,000	+11	NC	NC	203.39	NC	24.71	3.38	28.30	3.01	1.32
8,000	+ 9	NC	NC	NC	NC	NC	4.34	NC	3.81	1.49
9,000	+ 7	NC	NC	NC	NC	NC	5.97	NC	5.12	1.71
10,000	+ 5	NC	NC	NC	NC	NC	9.33	NC	7.68	1.99

NC = No Climb Capability

TABLE 12

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES +20°C

NORMAL CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
HOGE Limit (ft.)		-2,600	1,300	5,000	1,300	5,900	10,200	5,900	10,400	15,400
S.L.	+35	NC	16.51	3.78	15.65	2.92	1.48	2.77	1.37	0.75
500	+34	NC	27.83	4.24	26.37	3.23	1.57	3.06	1.45	0.82
1,000	+33	NC	83.41	4.82	78.84	3.59	1.67	3.40	1.54	0.85
1,500	+32	NC	NC	5.56	NC	4.04	1.79	3.83	1.65	0.89
2,000	+31	NC	NC	6.53	NC	4.59	1.91	4.36	1.76	0.94
2,500	+30	NC	NC	7.91	NC	5.32	2.06	5.05	1.89	0.98
3,000	+29	NC	NC	9.98	NC	6.30	2.22	5.98	2.04	1.03
3,500	+28	NC	NC	13.43	NC	7.70	2.41	7.31	2.21	1.08
4,000	+27	NC	NC	20.31	NC	9.84	2.62	9.34	2.40	1.14
4,500	+26	NC	NC	40.97	NC	13.54	2.88	12.85	2.65	1.21
5,000	+25	NC	NC	8132.70	NC	21.42	3.18	20.32	2.90	1.28
6,000	+23	NC	NC	NC	NC	NC	4.01	NC	3.64	1.44
7,000	+21	NC	NC	NC	NC	NC	5.35	NC	4.80	1.65
8,000	+19	NC	NC	NC	NC	NC	7.90	NC	6.97	1.91
9,000	+17	NC	NC	NC	NC	NC	14.52	NC	12.24	2.25
10,000	+15	NC	NC	NC	NC	NC	77.11	NC	45.95	2.72

NC = No Climb Capability

TABLE 13

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES +30°C

NORMAL CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
HOGE Limit (ft.)		-5,700	-2,000	2,500	-1,900	2,700	7,300	3,100	7,400	12,100
S.L.	+45	NC	NC	8.17	NC	6.99	2.31	5.75	2.14	1.12
500	+44	NC	NC	10.30	NC	8.64	2.51	6.89	2.32	1.18
1,000	+43	NC	NC	14.56	NC	11.23	2.73	8.59	2.52	1.25
1,500	+42	NC	NC	20.97	NC	15.93	3.00	11.36	2.76	1.32
2,000	+41	NC	NC	41.88	NC	26.89	3.31	16.53	3.04	1.40
2,500	+40	NC	NC	2501.25	NC	83.54	3.69	30.04	3.39	1.46
3,000	+39	NC	NC	NC	NC	NC	4.16	154.51	3.81	1.58
3,500	+38	NC	NC	NC	NC	NC	4.76	NC	4.34	1.69
4,000	+37	NC	NC	NC	NC	NC	5.54	NC	5.03	1.81
4,500	+36	NC	NC	NC	NC	NC	6.60	NC	5.96	1.95
5,000	+35	NC	NC	NC	NC	NC	8.14	NC	7.28	2.10
6,000	+33	NC	NC	NC	NC	NC	14.86	NC	12.95	2.59
7,000	+31	NC	NC	NC	NC	NC	72.61	NC	47.98	3.03
8,000	+29	NC	NC	NC	NC	NC	NC	NC	NC	3.84
9,000	+27	NC	NC	NC	NC	NC	NC	NC	NC	5.16
10,000	+25	NC	NC	NC	NC	NC	NC	NC	NC	7.75

NC = No Climb Capability

TABLE 14

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I: Percent Max. TOGW 100%	I: 90%	I: 80%	II: Percent Max. TOGW 100%	II: 90%	II: 80%	III: Percent Max. TOGW 100%	III: 90%	III: 80%
HOGE Limit (ft.)		2,600	4,200	7,300	6,000	9,600	12,700	12,000	15,000	18,100
S.L.	+15	5.91	3.62	1.94	2.23	1.26	0.88	0.86	0.64	0.49
500	+14	7.39	4.15	2.11	2.46	1.34	0.93	0.91	0.66	0.50
1,000	+13	9.79	4.84	2.29	2.73	1.44	0.98	0.96	0.70	0.52
1,500	+12	14.36	5.79	2.51	3.07	1.54	1.03	1.01	0.73	0.54
2,000	+11	26.56	7.17	2.78	3.48	1.66	1.09	1.08	0.76	0.57
2,500	+10	158.40	9.37	3.10	4.02	1.79	1.15	1.14	0.80	0.59
3,000	+ 9	NC	13.37	3.49	4.73	1.94	1.23	1.22	0.84	0.62
3,500	+ 8	NC	23.11	3.98	5.73	2.12	1.31	1.30	0.89	0.64
4,000	+ 7	NC	81.98	4.64	7.25	2.33	1.39	1.40	0.94	0.67
4,500	+ 6	NC	NC	5.51	9.75	2.58	1.49	1.50	0.99	0.71
5,000	+ 5	NC	NC	6.78	14.82	2.89	1.61	1.53	1.05	0.74
6,000	+ 3	NC	NC	12.23	NC	3.77	1.88	1.93	1.19	0.82
7,000	+ 1	NC	NC	54.24	NC	5.32	2.25	2.37	1.37	0.91
8,000	- 1	NC	NC	NC	NC	8.80	2.79	3.01	1.59	1.02
9,000	- 3	NC	NC	NC	NC	23.88	3.61	4.10	1.89	1.15
10,000	- 5	NC	NC	NC	NC	NC	5.05	6.26	2.32	1.32

NC = No Climb Capability

TABLE 15

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES +10°C

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
HOGE Limit (ft.)		700	2,400	6,200	4,300	8,200	11,600	10,300	14,000	17,000
S.L.	+25	21.75	6.75	2.32	3.30	1.53	1.02	1.06	0.70	0.53
500	+24	66.94	8.64	2.55	3.78	1.64	1.07	1.13	0.73	0.55
1,000	+23	NC	11.91	2.82	4.40	1.77	1.13	1.20	0.76	0.58
1,500	+22	NC	18.93	3.14	5.25	1.92	1.20	1.28	0.80	0.60
2,000	+21	NC	44.72	3.54	6.47	2.09	1.27	1.37	0.84	0.63
2,500	+20	NC	NC	4.05	8.39	2.29	1.36	1.48	0.89	0.65
3,000	+19	NC	NC	4.72	11.86	2.54	1.45	1.59	0.94	0.68
3,500	+18	NC	NC	5.62	19.93	2.83	1.56	1.73	0.99	0.72
4,000	+17	NC	NC	6.94	60.53	3.19	1.68	1.88	1.05	0.75
4,500	+16	NC	NC	8.99	NC	3.65	1.82	2.07	1.12	0.78
5,000	+15	NC	NC	12.70	NC	4.25	1.98	2.28	1.19	0.83
6,000	+13	NC	NC	64.35	NC	6.27	2.39	2.88	1.37	0.92
7,000	+11	NC	NC	NC	NC	11.49	2.99	3.83	1.59	1.04
8,000	+ 9	NC	NC	NC	NC	59.72	3.94	5.66	1.89	1.17
9,000	+ 7	NC	NC	NC	NC	NC	5.68	10.39	2.32	1.35
10,000	+ 5	NC	NC	NC	NC	NC	9.91	53.80	2.95	1.57

NC = No Climb Capability

TABLE 16

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES +20°C

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
HOGE Limit (ft.)		-3,500	1,000	3,300	1,000	5,800	9,600	7,000	12,600	15,900
S.L.	+35	NC	16.40	4.91	15.56	2.36	1.27	1.75	0.80	0.58
500	+34	NC	33.13	5.87	31.43	2.61	1.36	1.90	0.84	0.61
1,000	+33	NC	NC	7.23	NC	2.91	1.45	2.08	0.89	0.63
1,500	+32	NC	NC	9.39	NC	3.28	1.55	2.29	0.94	0.66
2,000	+31	NC	NC	13.22	NC	3.75	1.67	2.54	0.99	0.69
2,500	+30	NC	NC	22.24	NC	4.36	1.80	2.85	1.05	0.73
3,000	+29	NC	NC	66.89	NC	5.20	1.96	3.23	1.11	0.76
3,500	+28	NC	NC	NC	NC	6.42	2.14	3.73	1.19	0.80
4,000	+27	NC	NC	NC	NC	8.31	2.35	4.39	1.27	0.84
4,500	+26	NC	NC	NC	NC	11.74	2.60	5.31	1.36	0.89
5,000	+25	NC	NC	NC	NC	19.64	2.91	6.70	1.46	0.94
6,000	+23	NC	NC	NC	NC	NC	3.79	13.64	1.72	1.05
7,000	+21	NC	NC	NC	NC	NC	5.33	NC	2.06	1.19
8,000	+19	NC	NC	NC	NC	NC	8.80	NC	2.56	1.37
9,000	+17	NC	NC	NC	NC	NC	23.22	NC	2.32	1.60
10,000	+15	NC	NC	NC	NC	NC	NC	NC	4.68	1.91

NC = No Climb Capability

TABLE 17

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES +30°C

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	I Percent Max. 100%	I 90%	I TOGW 80%	II Percent Max. 100%	II 90%	II TOGW 80%	III Percent Max. 100%	III 90%	III TOGW 80%
HOGE Limit	(ft.)	-7,700	-3,200	1,200	-1,700	2,800	7,200	4,300	8,800	13,200
S.L.	+45	NC	NC	13.68	NC	5.45	1.83	3.15	1.33	0.77
500	+44	NC	NC	23.16	NC	6.72	1.99	3.60	1.43	0.81
1,000	+43	NC	NC	72.14	NC	8.72	2.17	4.19	1.53	0.85
1,500	+42	NC	NC	NC	NC	12.33	2.38	5.00	1.66	0.90
2,000	+41	NC	NC	NC	NC	20.62	2.63	6.16	1.79	0.94
2,500	+40	NC	NC	NC	NC	61.27	2.93	7.98	1.95	1.00
3,000	+39	NC	NC	NC	NC	NC	3.30	11.26	2.14	1.06
3,500	+38	NC	NC	NC	NC	NC	3.78	18.92	2.37	1.12
4,000	+37	NC	NC	NC	NC	NC	4.41	56.62	2.64	1.19
4,500	+36	NC	NC	NC	NC	NC	5.25	NC	2.98	1.27
5,000	+35	NC	NC	NC	NC	NC	6.48	NC	3.41	1.36
6,000	+33	NC	NC	NC	NC	NC	11.92	NC	4.73	1.58
7,000	+31	NC	NC	NC	NC	NC	61.69	NC	7.54	1.87
8,000	+29	NC	NC	NC	NC	NC	NC	NC	17.75	2.27
9,000	+27	NC	NC	NC	NC	NC	NC	NC	NC	2.85
10,000	+25	NC	NC	NC	NC	NC	NC	NC	NC	3.80

NC = No Climb Capability

Category helicopter could only achieve 41.88:1 at 80% of TOGW; Level II would have a marginal 26.89:1 capability at 90% of TOGW, but a good 3.31:1 at 80% of TOGW; and even Level III might require some downloading if, say, 8:1 performance were needed consistent with present heliport design standards.

The Direct Climb tables also list limiting HOGE altitudes by performance level for both Normal and Transport Category helicopters. These data are useful in assessing HMA requirements. Look again at the second example above -- 2000 feet pressure altitude, 30°C above standard day (Table 13 again). Assume that planning criteria states we should not require Level II helicopters to load below 90% of TOGW. What size HMA would be required to accelerate to 70 knots, and would the normal climb gradient be better than 8:1? Table 13 shows the limiting HOGE to be 2700 feet when temperatures are 30°C warmer than standard day, so HOGE is attainable with a margin at 90% of TOGW. Table 1 shows that, at 0.18g, acceleration to 70 knots requires 1297 feet.

Effect of Wind

The effect of wind has not been considered in any of the preceding discussions, from height-velocity considerations through acceleration distances and rejected takeoff distances to climb gradients. Headwind has a universally beneficial effect on these aspects of performance, and tailwinds a universally adverse effect. The direction and magnitude of wind velocity vectors are not reliably predictable for long range planning purposes. Thus, for heliports offering similar flight paths on either of two reciprocal headings, zero wind conditions are appropriate to the planning evolution. When there is only one way in and the way out is its reciprocal, the adverse effects of tailwind should be taken in account.

HELIPORT CLASSIFICATION SCHEME

This section describes a suggested classification scheme for use in heliport planning and subsequent description in the Airman's Information Manual (AIM) and other appropriate listings. After developing the performance level approach to evaluating helicopter capabilities, it is very tempting to suggest extension of performance level classifications to both heliports and helicopters. This is not suggested in the following discussion because the heliport, once established, has enduring physical features which define the real estate and airspace available to helicopter operators. The helicopter, on the other hand, is subject to great variations in capability which depend on: wind and weather variations beyond the operator's control; and weight and equipment variations that are within his control. Consequently, the heliport classification scheme suggested herein is based on the functions the heliport is intended to satisfy and the relationship of its physical features to performance parameters of interest to operators.

Basic Classification Scheme

Reference 1 recommended additional classifications for heliports which reflected the type of operation, rather than the type of user. They are adopted here as the basic classification framework within which performance-oriented sub-classifications can be applied. They identify four types of heliports/operations and their definitions are reproduced here.

VISUAL HELIPORT means a heliport intended solely for the operation of helicopters using visual approach procedures, with no helicopter instrument approach or departure procedure, and no instrument designation indicated on any heliport planning document recognized by the FAA.

NON-PRECISION INSTRUMENT HELIPORT means a heliport having an existing instrument approach procedure utilizing air navigation facilities with only horizontal guidance, or area type navigation equipment, for which a straight-in non-precision instrument approach procedure has been approved or planned, and for which no precision approach facilties are planned or indicated on any

heliport planning document recognized by the FAA. It may or may not have an approved instrument departure.

PRECISION INSTRUMENT HELIPORT means a heliport having an existing instrument approach procedure utilizing an Instrument Landing System (ILS), the future Microwave Landing System (MLS), or a Precision Approach Radar (PAR). It also means a heliport for which a precision approach system is planned and is so indicated by a heliport planning document recognized by the FAA. It may or may not have an approved instrument departure.

INSTRUMENT DEPARTURE HELIPORT means a heliport which may or may not have an instrument approach procedure, but has been developed and is approved for instrument departures by an FAA-approved Helicopter Instrument Departure Procedure.

Extended Classification Scheme for Planning Purposes

Beyond the basic operational classifications originally suggested in Reference 1 and reviewed in the preceding discussion, it is suggested that two sub-classes be established to identify whether a maneuver area is available to permit IGE acceleration on departure or post-approach deceleration on arrival. The designations selected reference the Heliport Maneuver Area, and are: HMA-1 and HMA-2.

A "HMA-1" heliport definition is suggested that would require a HMA permitting at least enough space for acceleration to 40 knots at 0.18g (400 feet). The HMA should be reserved for maneuvering use by arriving and departing aircraft, just as a runway would be. It should not be utilized for aircraft parking or servicing unless an interim or revised sub-classification is established by a Notice to Airmen.

The principal axis orientation of the HMA (if oblong) and its dimensions should be published for ready access to using pilots and the protected climb (approach) surfaces defined if above some arbitrary minimum value associated with a most demanding type of use (say, 53:1 associated with the Horizontal

Profile OEI takeoff procedures for Transport Category A helicopters). For the immediate future, all INSTRUMENT DEPARTURE HELIPORTS would necessarily be HMA-1 heliports to accommodate acceleration to minimum IFR airspeed or IFR climb speed. Review of limiting HOGE altitudes would imply that most heliports located above 3000 or 4000 feet should be HMA-1.

A second sub-class identified as "HMA-2" is suggested to include heliports for which an HMA of less than 400 feet is provided. Although the axis orientation of a small landing area is many times not significant enough to warrant publication, it should be included along with the orientation of approach and departure paths, and the protected gradients should be published, as for HMA-1 heliports. The dimensions of the landing area (HMA) should also be listed. Either Direct Profile or Vertical Profile departures could be conducted from HMA-2 heliports, but OEI gradients (about 53:1 from 35 feet above the landing area) should be provided if Transport Category A utilization is to be supported. HMA-2 heliports could inlcude VFR HELIPORTS and both PRECISION and NON-PRECISION INSTRUMENT HELIPORTS. Transport helicopters of both Category A and B can utilize Direct Profile approach procedures whenever Direct Climb gradient capability equals or exceeds the needed approach gradient. Thus, the lack of a substantial HMA should not be considered a deterent in itself to landing operations of Transport Category helicopters or, given appropriate ceiling and visibility, to landing operations associated with instrument approach procedures.

HMA-2 heliports, as defined herein, would not be capable of supporting instrument departure procedures unless adequate ceilings existed to permit Direct or Vertical Flight Profile takeoffs to be completed clear of clouds to attain the minimum IFR airspeed (or IFR climb speed if applicable).

Future Requirements for Instrument Heliport Classifications

Present airworthiness requirements for the certification of helicopters for IFR operation result in clearly tailored flight envelopes -- primarily in airspeed, and occasionally in vertical speed. This prevents helicopters from fully utilizing, under IMC, the various performance capabilities which are

common to VMC operations. Thus, the real estate and airspace requirements for the two IFR classifications (precision approach and instrument departure) are limited by state-of-the-art certification.

At least one event can be anticipated which could allow reduced baseline values in the future -- namely, decelerating or slow, steep precision approaches. Flight testing and evaluation continues in an effort to determine helicopter capabilities in this regard, and to identify the necessary equipment and flying qualities prerequisites which must accompany such approaches.

It is possible, given improved avionics and displays, and appropriate redundancy in stability and control augmentation, that precision approaches with deceleration to a hover will be possible with approach angles or glide path angles of 6° to 9° in the future. This could well make precision instrument approach procedures acceptable or practical at heliports which presently are capable of supporting only VFR or SVFR operations.

The real estate requirements for instrument departure also have the potential of being reduced. This could become possible through certification of the near vertical instrument takeoff referenced earlier for zero-zero, or nearly so, ceiling-visibility conditions. Direct Climb takeoffs (Direct Flight Profile) would be appropriate provided instrumentation displays and handling qualities permitted certification for IMC flight in slow speed, accelerating, climbing flight. Transport Category A helicopters operated in such instrument takeoff and departure procedures would not be able to perform Vertical Profile takeoff procedures under IMC conditions before reaching takeoff safety speed. Ceilings for Transport Category A departures under such circumstances would have to be adequate to make the full vertical climb and transition to TOSS or minimum IFR airspeed under VMC conditions. Given the instrumentation display and handling qualities to permit IMC flight in a slower speed regime, future developments would most probably result in production of Transport Category A helicopters with an OEI hover capability. Thus TOSS would become, for such aircraft, zero airspeed and the critical decision point would occur when ready to depart from the initial IGE hover reached immediately after takeoff.

SUMMARY

Since descent and deceleration performance capabilities are assured within limiting acceleration and climb capabilities, the total real estate and airspace requirements may be determined by computing the HMA and the departure flight profile required for the specific helicopters to be operated from a heliport. As helicopter performance is the primary factor in determining these parameters, it becomes the baseline criteria. However, performance is a function of weight, altitute and temperature so no single performance figure can be assigned to a given helicopter.

It was the goal of this study to present heliport planning criteria based on baseline conditions of WAT that apply to helicopters and then develop formulae for accommodating deviations from the baseline. This has in fact been done, and the manner of presentation provides a spectrum of baselines which offers performance planning data to support heliport planning between sea level and 10,000 feet (pressure altitude) for temperatures ranging from standard day to 30°C warmer than standard day.

The Heliport Manuever Area size is determined by the distance required to accelerate to a given climb airspped in order to meet a specific departure profile. In this study, three flight profiles were developed which identify all potential terminal maneuvers. The Horizontal Flight Profile which requires a relatively large Heliport Maneuver Area; the Direct Flight Profile which requires no appreciable HMA; and the Vertical Flight Profile which is defined for use by Transport Category A helicopters. Each flight profile requires different real estate requirements and the ability of a given helicopter to utilize a specific profile is dependant upon its level of performance.

A variety of helicopter design parameters which influence performance were analyzed. These parameters were used to establish three Levels of Performance within each of the two helicopter certification categories - Normal and Transport. The data presented were based on a baseline helicopter in each of these categories.

Utilizing the performance achievable at each of the three performance levels, data are presented in tabular form for both the Conventional and Direct climb profiles. Data are presented (for both Normal and Transport Category helicopters) for pressure altitudes ranging from sea level to 10,000 feet and for four temperature levels. The temperature levels are standard day conditions for each altitude and conditions of 10°C, 20°C, and 30°C hotter than standard day. A further breakdown was made to show the effect of off-loading weight by showing climb gradients for each of three proportional weights -- 100%, 90% and 80% of the limiting TOGW. 80% of TOGW is an approximation of the minimum weight for a productive load.

Utilizing the data presented in this report, a heliport planner can determine first the HMA required and then, based upon the desired/required climb profile, he can determine the specific climb gradient that can be expected, for a Performance Level I, II or III helicopter based on his heliports pressure attitude and temperature standard. The planner will also be able to determine a percentage reduction in TOGW that may be required by each Performance Level to meet a specific gradient for his present or planned heliport.

Now heliport planners, through this document, can have in hand information not generally available to the helicopter pilots who must fly the aircraft to and from the heliports designed for their benefit. It is granted that Conventional Climb data are usually provided in the RFM in the form of best rate of climb. This permits computation of climb angle or gradient if V_y is known. Suprisingly, two helicopter RFM's examined did not reveal V_y!

But Direct Climb data is not available in any form. The computational procedure used herein could be accomplished by pilots during flight planning, but it is tedious and presupposes pilot access to extensive data on the characteristics of a standard atmosphere. If heliports are to be developed based on a knowledgeable, general appreciation of helicopter performance capabilities, then they certainly should be used with an explicit appreciation of the precise helicopter capabilities which may be expected in conjunction with the known heliport real estate and airspace constraints, as tempered by reasonable expectations of the weather.

Both Normal Category and Transport Category helicopters need in their RFM several items of performance data not universally provided, and some items not provided at all. These former items include HIGE and HOGE performance and rate of climb at V_y for takeoff and maximum continous power. These data are usually, but not always, provided. The latter category includes vertical rate of climb or Direct Climb data similar to that provided herein for the generic helicopter performance classifications, and climb data for the best angle of climb which avoids H-V limitations. Similar data are needed for OEI operations to the extent to which they apply. All data should be presented in a readily interpreted manner which will enable pilots to compare the capabilities of their aircraft to the requirements posed by particular heliports experiencing specific weather phenomena.

Heliport planners should know the capabilities of the helicopters they hope to serve, and they should strive to accommodate the maximum feasible utility. This report is intended to provide data about the general nature of helicopter capabilities supportive of that end. Functional classification at heliports by the nature of terminal procedures is urged with subclassification and description that details the physical characteristics of heliport real estate and associated airspace. Elements of that description are summarized in Table 18.

Aircraft performance data that permits full exploitation of aircraft capabilities consistent with the detailed heliport information proposed is urged. Coincident efforts from both sides, aircraft and heliport operators, will expand the utility of both aircraft and heliport operations and the safety of all concerned.

TABLE 18

DATA REQUIREMENTS FOR PUBLICATION

IN HELIPORT FACILITIES DIRECTORY OF AIM SUPPLEMENT

Heliport User Category	Public, Private, etc.
Heliport Operational Classification	VFR, Precision Approach, etc.
Heliport Maneuver Area Sub-Classification	HMA-1 or HMA-2
Flight Path Angle/Gradient	each approach departure path
Heliport Landing/Maneuver Area Dimensions	length width
Heliport Maneuver Area	principal axis orientation
Elevation (of Takeoff Landing Area)	ft. (MSL)
Elevated Helipads (Height Above Ground)	ft. (AGL)

Heliport Diagram with Traffic (approach/departure paths)

Pressure Altitude/Altimeter Setting Source.

(From 29.92 each +0.10 in Hg = -100 ft. P.A. from published elevation MSL to determine ambient pressure altitude.)

APPENDIX A

DEFINITIONS AND TERMINOLOGY

The research reported in this document involved review and analysis of a number of criteria, regulations and related publications which comprised a data base of considerable scope. In order to enhance the clarity and understanding of the discussions contained in this report, pertinent definitions of terms are offered here. Where appropriate, they are reproduced verbatim and the source identified.

EFFECTIVE TRANSLATIONAL LIFT (ETL): The point at which the pilot can sense a reduction in power required as airspeed increases. The onset of ETL typically occurs at 15-25 knots airspeed for most helicopters.

GROUND EFFECT: An improvement in flight capability that develops whenever the helicopter flies or hovers near the ground or other surface. It results from the cushion of denser air built up between the ground and the helicopter by the air displaced downward by the rotor. (Reference 1)

HELIPORT: An area of land, water, or structure used or intended to be used for the landing and takeoff of helicopters. (FAR Part 1)

HELIPORT CLASSIFICATION: The terms used to classify United States Heliports are descriptive of the class of user allowed to conduct flight operations from the facility. (Reference 1)

> Federal Heliport. The term "Federal heliport" is applied to heliport facilities operated by a nonmilitary agency or department of the United States Government. Most Federal heliports are operated by the Departments of Agriculture (DOA) and Interior (DOI). DOA and DOI heliports are located in national forests or national parks and are used to carry out departmental responsibilities for land management and fire suppression activities. Generally, DOA and DOI heliports are restricted to departmental usage.

Public-Use Heliport. The term "public-use-heliport" is applied to any heliport that is open to the general public and does not require prior permission of the owner to land. However, the extent of facilities provided may limit operations to helicopters of a specific size or weight. A public-use heliport may be owned by a public agency, an individual, or a corporation so long as it is open for public use. Public-use heliports are listed in the Airman's Information Manual (AIM) and may be depicted on appropriate aeronautical charts.

Private-Use Heliport. The term "private-use heliport" is applied to any heliport that restricts usage to the owner or to persons authorized by the owner. Most private-use heliports are owned by individuals, companies, or corporations. However a heliport designated as "private-use" may be owned by a public body. In this case, the private-use classification is applicable because the facility is restricted to a specific type of user, such as the police department, or because the owner requires prior permission to land. Hospital heliports are considered private-use facilities since operations are normally restricted to medical-related activities. Private-use heliports are not listed in the AIM but may be depicted on aeronautical charts.

Personal-Use Heliport. The term "personal-use heliport" is applied to any heliport that is used exclusively by the owner. Personal-use heliports are owned by individuals, companies, or corporations. Personal-use heliports are not listed in the AIM but may be depicted on aeronautical charts.

Helicopter Landing Site. As noted previously, helicopters are capable of being operated into cleared areas only slightly larger than the helicopter itself. It is this versatility that enables the pilot of a helicopter to land at the scene of an accident, on the roof of a burning building, near a construction site, etc. In each case the decision to land is made by the pilot who must weigh the operational necessity for the landing against the helicopter's performance capabilities,

physical limitations of the site, and his or her piloting skills. For the most part, these are one-time, temporary, or infrequent operations, and the landing site should not be considered a heliport.

HELIPORT APPROACH SURFACE: The approach surface begins at each end of the heliport primary surface with the same width as the primary surface, and extends outward and upward for a horizontal distance of 4,000 feet where its width is 500 feet. The slope of the approach surface is 8 to 1 for civil heliports and 10 to 1 for military heliports. (FAR Part 77)

HELIPORT ELEVATION: The elevation of the takeoff and landing area and the heliport primary surface.

HELIPORT PRIMARY SURFACE: The area of the primary surface coincides in size and shape with the designated takeoff and landing area of a heliport. This surface is a horizontal plane at the elevation of the established heliport elevation. (FAR Part 77)

HELIPORT TRANSITIONAL SURFACES: These surfaces extend outward and upward from the lateral boundaries of the heliport primary surface and from the approach surfaces at a slope of 2 to 1 for a distance of 250 feet measured horizontally from the centerline of the primary and approach surfaces. (FAR Part 77)

INSTRUMENT FLIGHT RULES (IFR): Rules that govern the procedures for conducting instrument flight.

OBSTACLE: Any object which does not exceed an obstacle clearance plane.

OBSTRUCTION: An object which penetrates a prescribed obstacle clearance plane or surface.

PARKING AREA (Apron or Ramp): A defined area on the heliport intended to accommodate helicopters for purposes of loading or unloading passengers or cargo, refueling, parking, or maintenance.

PERIPHERAL AREA: An obstruction-free area adjacent to the takeoff and landing area serving as a safety zone.

TAKEOFF AND LANDING AREA: A designated area on the heliport which is coincident with the heliport primary surface and the boundaries of which are used to establish the FAR Part 77.29 imaginary surfaces. These surfaces are used for determining obstructions to air navigation. As such, it is the heliport area from which helicopter departures and approaches are intended to originate or terminate.

TAXIWAY: A designated, but not necessarily paved, path or route for helicopters to taxi from one heliport area to another.

TERMINAL INSTRUMENT PROCEDURES (TERPS): Procedures for instrument approach and departure of aircraft to and from civil and military airports.

TOUCHDOWN PAD: The load-bearing portion of the heliport's designated takeoff and landing area on which a helicopter may alight.

VISUAL FLIGHT RULES (VFR): Rules that govern the procedures for conducting flight under visual conditions.

APPENDIX B

ANALYTICAL BASIS FOR HELICOPTER PERFORMANCE ESTIMATES

INTRODUCTION

To satisfy the purpose of the basic report, quantitative estimates of three major aspects of helicopter performance are needed. These are:

(1) distance to accelerate between no wind hover and appropriate climb speeds in horizontal flight (or, conversely, decelerate from approach speed);

(2) climb gradient sustainable with maximum continuous power at best rate of climb airspeed; and

(3) climb gradient for a direct, accelerating climb initiated directly from the hover at takeoff power rating.

This appendix documents the analytical methods used to obtain these estimates, the simplifying assumptions associated with these methods, and the performance data used as the basis for statistical generalizations.

It should be recognized at the outset that the analytical methods used herein are intended to provide only crude approximations. The focus of this whole study is on capabilities of helicopters in general not on the capabilities of any specific helicopter in detail; consequently, parameters of a real helicopter entered into the equations for performance estimation should not be expected to produce exactly the same results contained in the Rotorcraft Flight Manual (RFM) or other reliable source of the manufacturer's performance estimate. These differences result partly from the simplifying assumptions used in the analyses and partly from the need to generalize the estimates for widespread applicability. Hence, whenever performance of a specific model helicopter is at issue, its flight manual should be consulted.

ACCELERATION (DECELERATION) ESTIMATION

The horizontal distance required to accelerate from a no wind hover to some appropriate climbing airspeed is not directly controlled by performance capability of the helicopter in question. It is, rather, more a function of practical maneuver limits. The attainable acceleration rate in "g" units is merely the tangent of the angle through which the helicopter rotates nose down from its hover attitude to initiate the acceleration. This change in attitude is limited to about 10° when passenger confidence or comfort must be considered. The resulting acceleration rate is .18g, and the corresponding increase in thrust to sustain altitude during the acceleration is about 1.5% (secant of rotation angle - 1 , converted to percentage). For typical hover figures of merit (see Reference 10 for more detail) the 1.5% increase in thrust requires about 1% more power than was needed to sustain the hover. Such increases are readily possible at all altitudes less than the limiting altitude for hover out of ground effect (HOGE). While more extreme changes of attitude are possible and sometimes utilized when no passengers are embarked and takeoff weight is light, standards for acceleration distance should be based on procedures comfortable to helicopter passengers, thus the suggested limit of 10°.

When HOGE is no longer possible but the helicopter is not yet operated at its limiting altitude for hover in ground effect (HIGE), a more conservative maneuver is required by the power available. In practice, the pilot will rotate slightly nose downward to initiate acceleration, verify that he has sufficient power to sustain altitude, and rotate further while he gains the maximum sustainable acceleration rate. This process may be approximated by a 5° nosedown rotation from the hover attitude. This results in a .09g acceleration rate which requires 0.4% more thrust and about 0.3% more power than hovering.

Table 1 of the basic report is based on the following relationships for acceleration.

Acceleration rate = tangent angular change in attitude

$$\frac{\text{Thrust required to accelerate}}{\text{Thrust required in hover}} = \text{secant angular change in attitude}$$

$$\text{Distance required to accelerate} = \frac{1}{a}\int_{0}^{TAS} v\,dv = \frac{(TAS)^2}{2x32.2xg}$$

in which a = 32.2 (ft/sec2) x the acceleration rate in "g" units. These approximations are equally valid for estimation of horizontal deceleration. Assumptions implicit in these equations include:

(1) Acceleration rate is assumed to be sustained at a constant value throughout the maneuver.

(2) Consequently, drag can be neglected in defining distance required. This introduces minor errors in angular change in attitude, thrust and power which may be neglected for modest values of climbing (or approach) airspeed say up to about 70 knots.

ESTIMATION OF GRADIENT FOR CONVENTIONAL CLIMB AT BEST RATE OF CLIMB AIRSPEED (Vy)

The initial approach taken in attempting estimation of "Conventional Climb" performance was to review the performance capabilities revealed in the rotorcraft flight manuals of as many different helicopters as possible. Correlation was then attempted between performance variables such as rate of climb or climb angle and design parameters such as disc loading, power loading, tip speed, advance ratio, et cetera. For the sample size available, no statistically significant correlations were identified. These data, gathered from a variety of sources, are shown in Tables B-1 through B-3.

TABLE B-1A

PERFORMANCE DATA AND SPECIFICATIONS

NORMAL CATEGORY ROTORCRAFT

	Aerosp. SA-315B	Aerosp. SA-316B	Aerosp. SA-341G	Aerosp. AS-350D	Agusta 109A
Takeoff Gross Weight (lbs)	4300	4850	3970	4190	5400
No of Engines	1	1	1	1	2
Normal Power Limit (HP)	562	542	494	531	692
OEI Power Limit (HP)	-	-	-	-	400
Rotor Speed (RPM)	353	353	378	385	385
No of Blades	3	3	3	3	4
Rotor Diameter (ft)	36.2	36.1	34.4	35.1	36.1
Disc Area (sq ft)	1026	1023	932	966	1023
Blade Area (sq ft)	62	62	51	NG	79
Solidity	.061	.061	.054	-	.077
Disc Loading (lb/ft2)	4.2	4.7	4.3	4.5	5.6
Blade Loading (lb/ft2)	69.0	77.9	78.1	-	72.4
Normal Power Loading lb/HP)	7.7	9.0	8.0	8.1	7.8
OEI Power Loading (lb/HP)	-	-	-	-	13.5
Vy (Kts)	51	55	65	55	60
V_{TOSS} (Kts)	-	-	-	-	NG
Rejected Takeoff Dist. (ft)	-	-	-	-	NG

TABLE B-1B

PERFORMANCE DATA AND SPECIFICATIONS

NORMAL CATEGORY ROTORCRAFT

	Bell 47G4A	Bell 206B	Bell 206L-1	Brantly B2B	Brantly 305	Enstrom F-28A
Takeoff Gross Weight (lbs)	2950	3200	4050	1670	2900	2150
No of Engines	1	1	1	1	1	1
Normal Power Limit (HP)	280	317	435	180	305	205
OEI Power Limit (HP)	-	-	-	-	-	-
Rotor Speed (RPM)	370	394	394	NG	NG	330
No of Blades	2	2	2	3	3	3
Rotor Diameter (ft)	37.1	33.3	37.0	23.8	28.7	32.0
Disc Area (sq ft)	1082	873	1075	443	645	804
Blade Area (sq ft)	34	36	40	22	36	38
Solidity	.031	.041	.037	.050	.056	.047
Disc Loading (lb/ft^2)	2.7	3.7	3.8	3.8	4.5	2.7
Blade Loading (lb/ft^2)	86.7	88.6	101.0	75.0	88.9	56.6
Normal Power Loading lb/HP)	10.5	10.1	9.3	9.3	9.8	10.5
OEI Power Loading (lb/HP)	-	-	-	-	-	-
Vy (Kts)	43	52	52	NG	NG	50
V_{TOSS} (Kts)	-	-	-	-	-	-
Rejected Takeoff Dist. (ft)	-	-	-	-	-	-

TABLE B-1C

PERFORMANCE DATA AND SPECIFICATIONS

NORMAL CATEGORY ROTORCRAFT

	Hiller FH-1100	Hiller UH-12E	Hughes 269C	Hughes 369D	MBB BO-105C	Robinson R-22
Takeoff Gross Weight (lbs)	2750	2750	2050	3000	5070	1300
No of Engines	1	1	1	1	2	1
Normal Power Limit (HP)	270	305	190	375	364	124
OEI Power Limit (HP)	-	-	-	-	371	-
Rotor Speed (RPM)	375	NG	533	492	425	530
No of Blades	2	2	3	5	4	2
Rotor Diameter (ft)	35.4	35.4	26.8	26.4	32.3	25.2
Disc Area (sq ft)	985	985	566	548	819	497
Blade Area (sq ft)	30	33	21	37	57	15
Solidity	.031	.033	.038	.068	.070	.030
Disc Loading (lb/ft2)	2.8	2.8	3.6	5.5	6.2	2.6
Blade Loading (lb/ft2)	91.2	84.4	96.3	80.9	88.6	86.[illegible]
Normal Power Loading lb/HP)	10.0	9.0	10.8	8.0	8.0	10.5
OEI Power Loading (lb/HP)	-	-	-	-	13.7	-
Vy (Kts)	49	NG	43	60	63	NG
V_{TOSS} (Kts)	-	-	-	-	45	-
Rejected Takeoff Dist. (ft)	-	-	-	-	886	-

TABLE B-2

PERFORMANCE DATA AND SPECIFICATIONS

TRANSPORT CATEGORY A ROTORCRAFT

	Aerosp. SA-330J	Aerosp. SA-365C	Bell 212	Boeing 107-II	Sikorsky S-61N	Sikorsky S-76A
Takeoff Gross Weight (lbs)	16,300	7,500	10,000	17,900	19,000	10,000
No of Engines	2	2	2	2	2	2
Normal Power Limit (HP)	2427	1006	1300	2440	2500	1300
OEI Power Limit (HP)	1555	667	983	1350	1500	700
Rotor Speed (RPM)	265	350	324	264	203	313
No of Blades	4	4	2	6	5	4
Rotor Diameter (ft)	49.5	38.3	48.0	51.0	62.0	44.0
Disc Area (sq ft)	1924	1154	1810	4086	3019	1521
Blade Area (sq ft)	194	97	94	239	200	114
Solidity	.101	.084	.052	.059	.066	.075
Disc Loading (lb/ft2)	8.5	6.5	5.5	4.4	6.3	6.6
Blade Loading (lb/ft2)	84.1	77.0	106.9	74.9	95.2	88.0
Normal Power Loading lb/HP)	6.7	7.5	7.7	7.3	7.6	7.7
OEI Power Loading (lb/HP)	10.5	11.2	10.7	13.3	12.7	14.3
Vy (Kts)	70	70	55	83	70	74
V_{TOSS} (Kts)	45	45	30	NG	NG	52
Rejected Takeoff Dist. (ft)	1000	1150	2300	NG	NG	1410

TABLE B-3

PERFORMANCE DATA AND SPECIFICATIONS

TRANSPORT CATEGORY B ROTORCRAFT

	Aerosp. SA-360C	Bell 204B	Bell 205A1	Bell 214B	Bell 222	Sikorsky S-58T
Takeoff Gross Weight (lbs)	6,400	8,500	9,500	13,800	7,850	13,000
No of Engines	1	1	1	1	2	2
Normal Power Limit (HP)	871	1100	1250	2050	875	1625
OEI Power Limit (HP)	-	-	-	-	696	970
Rotor Speed (RPM)	349	324	324	300	338	248
No of Blades	4	2	2	2	2	4
Rotor Diameter (ft)	37.7	48.0	48.0	50.0	39.8	56.0
Disc Area (sq ft)	1118	1810	1810	1964	1241	2463
Blade Area (sq ft)	86	84	84	138	95	153
Solidity	.077	.046	.046	.070	.076	.062
Disc Loading (lb/ft2)	5.7	4.7	5.3	7.0	6.3	5.3
Blade Loading (lb/ft2)	74.0	101.2	113.1	100.4	82.9	84.9
Normal Power Loading lb/HP)	7.4	7.7	7.6	6.7	9.0	8.0
OEI Power Loading (lb/HP)	-	-	-	-	11.3	13.4
Vy (Kts)	70	55	55	70	65	NG
V_{TOSS} (Kts)	-	-	-	-	40	NG
Rejected Takeoff Dist. (ft)	-	-	-	-	NG	NG

The next approach was theoretical in which an expression was sought that succinctly described climb performance in a manner which would permit comparison with RFM data. Such an expression has been derived from basic momentum theory and has been utilized to project climb performance for different classes of helicopters. The momentum theory performance expression shows very strong correlation with performance capabilities determined from RFM for single main rotor helicopters. (The sole tandem rotor helicopter did not correlate because, with overlapping main rotors, it was too difficult to define the effective disc area.)

Classification of aircraft into performance categories could have been accomplished by a variety of partitions. The division selected separates helicopters into two classes by takeoff gross weight (TOGW). This division is a natural and logical outgrowth of certification requirements which impose different standards for "Normal" helicopters (less than 6000 lb TOGW) and "Transport" helicopters (greater than 6000 lb TOGW). Further subdivision by other significant features, such as single engine versus multi-engine, reduced the statistical significance of correlation by reducing sample sizes too much for practical application. (Only two multi-engine helicopters were members of the Normal Category, for instance.)

Within each class of helicopter, three performance levels have been defined. These are approximately related to 95% confidence intervals on the mean performance such that:

Level I -- most modern helicopters equal or exceed the capabilities of Level I.

Level II -- represents the mean performance; i.e., approximatly half of modern helicopters exceed this level and half fall short of Level II.

Level III -- few modern helicopters exceed the capabilities of Level III.

Levels I and III, then, denote lower and upper bounds, respectively, on the likely range of performance for modern, single main rotor helicopters. ("Modern" reflects the design practices which dominate the period 1960-1980.) Some earlier helicopter designs do not achieve performance Level I; conversely, future helicopter designs could readily exceed level III as defined herein if the designers become motivated to increase the proportion of installed power and provide rotor capability to utilize that power.

The relationships for climb performance estimation were developed from basic helicopter performance theory as contained in Reference 17, Principles of Helicopter Performance; Richards, R.B., published by the U.S. Navy for use as a textbook in the U.S. Navy Test Pilot School.

From Richards

Main Rotor Power = Induced Power + Profile Power + Parasite Power

$$= \frac{W^2}{2\rho\pi R^2 V_y} + WV_v \qquad \text{(Induced Power Terms)}$$

$$+ \frac{\sigma}{8}\rho\pi R^2 \bar{c}_{d_o} (\Omega R)^3 (1+4.65\mu) \qquad \text{(Profile Power Terms)}$$

$$+ \rho V_y \pi R^2 C_{D_p} \qquad \text{(Parasite Power Terms)}$$

in which:

W = aircraft weight

ρ = air density

R = rotor radius

V_y = flight path airspeed (for best rate of climb)

V_v = vertical component of flight path velocity

σ = rotor solidity (blade area divided by disc area)

$\bar{c}_{d_o}$ = mean section profile drag coefficient of the rotor blade

Ω = rotor rotational speed

μ = advance ratio (flight path airspeed divided blade tip speed)

C_{D_p} = drag coefficient of the aircraft fuselage

The induced power terms are, from momentum theory, the power utilized to generate lift; the profile power term represents the power required to rotate the rotor blades in a viscous fluid (air); and the parasite power term

represents the power required to sustain translating motion of the aircraft through the air. Insufficient information is published in RFM to directly evaluate the main rotor power, so a simplifying assumption is made which is valid for a sustained climb at constant airspeed and fixed power (such as takeoff or maximum continous power settings).

Induced power is constant, i.e. :

$$\frac{W^2}{2\rho\pi R^2 V_y} + WV_v = K_1$$

Eqn. (1)

K_1, is, for now, an arbitrary constant; but all of the parameters in the left hand side of Equation (1) are published in most RFM.

It is convenient for analysis and computational purposes to modify Equation (1) into non-dimensional form as follows:

$$\frac{(\Omega R)^2}{2V_y} \cdot \frac{W^2}{\rho\pi R^2(\Omega R)^2} \cdot \frac{1}{\rho\pi R^2(\Omega R)^2} + V_v \cdot \frac{W}{\rho\pi R^2(\Omega R)^2} = \frac{K_1}{\rho\pi R^2(\Omega R)^2} = K_2$$

Since the thrust coefficient $C_T = \frac{W}{\rho\pi R^2(\Omega R)^2}$, this becomes

$$\frac{(\Omega R)^2}{2V_y} \cdot C_T{}^2 + V_v C_T = K_2$$

Eqn (2)

Completing the transition to nondimensional form in which sin (the climb angle) = V_v/V_y and $\mu = V_y/\Omega R$

$$\frac{1}{V_y} \cdot \frac{(\Omega R)^2}{2V_y} \cdot C_T^{\,2} + \frac{V_v}{V_y} \cdot C_T = \frac{K_2}{V_y} = K_3$$

or

$$\sin\gamma\, C_T + \frac{1}{2}\left(\frac{C_T}{\mu}\right)^2 = K_3$$

Eqn. (3)

After computing K_3 from this expression based on the parameters available from RFM of the sample aircraft, it was found that the values of K_3 have a strong correlation with TOGW for the sample aircraft. Figure B-1 shows the regression line (Level II) and the lower and upper bounds (Levels I and III respectively) along with the data points for the sample helicopters. The correlation coefficient for the logarithmic regression line is .88. K_3 is a non-dimensional coefficient which represents the power available at the main rotor to produce lift. This coefficient is a measure of power available and not a direct measure of climbing performance. K_3 varies directly as a quadratic function of the thrust coefficient which, in turn, varies inversely with disc area. Performance tradeoffs by helicopter designers , which result in proportionately large disc area (low disc loading) or high tip speed, may result in good climbing performance despite a low value of K_3. Conversely, a high K_3 does not ensure good climb performance because design tradeoffs may generate the opposite effect.

Using limiting and median levels of K_3 to develop generic estimates of climb performance is practical by using mean values of the influencing design parameters of disc area and tip speed, which determine thrust coefficient, and

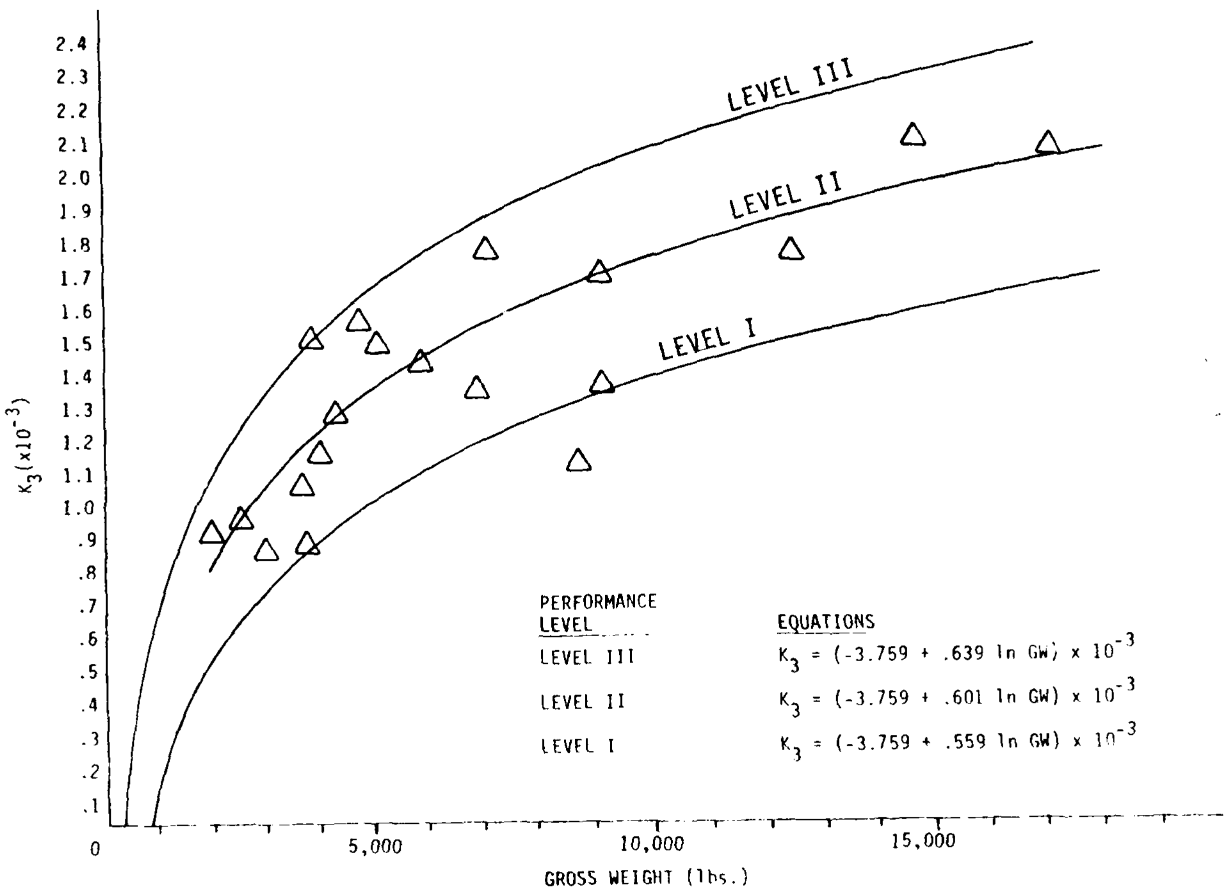


Figure B-1. Correlation of K_3 with Gross Weight

advance ratio which appears in Equation (3). This equation has been modified to provide climb performance estimates as follows:

$$\sin\gamma = \frac{1}{C_T}\left[K_3 - \frac{1}{2}\left(\frac{C_T}{\mu}\right)^2\right]$$

which can be further modified to estimate climb gradient as:

$$\text{gradient} = \text{ctn}\,\gamma = \text{ctn}\,\sin^{-1}\left\{\frac{1}{C_T}\left[K_3 - \frac{1}{2}\left(\frac{C_T}{\mu}\right)^2\right]\right\} \qquad \text{Eqn. (4)}$$

To use Equation (4) as a basis for generic estimates of helicopter climb performance, values of K_3 were computed for all helicopters for which sufficient data were presented in their respective RFM. K_3 was computed for sea-level standard day conditions at maximum takeoff gross weight using published data for rate of climb at V_y at maximum continous power. In computing climb gradients, an empirical correction factor has been applied to K_3 for altitude and temperature conditons which deviate from sea-level standard day conditions by substituting into Eq. (4) K_3' in which:

$$K_3' = \delta \cdot \frac{288}{288+2.5\,\Delta T} \cdot K_3$$

is the ratio of pressure at the altitude for which the computation is based to sea-level standard pressure and T its the temperature difference in degrees Celsius or (Kelvin) between standard and sample conditions. 288 is standard day absolute temperature (degrees Kelvin) and 2.5. is an arbitrary, empirical multiplier which most typically reflects the degree of power degradation with increasing temperature demonstrated by the helicopters in the data base. This empirical correction is biased on the conservative side and

accounts for varying degrees of flat rating of helicopter power among the helicopters in the sample as well as their actual power degradation with increasing temperature and altitude.

Table B-4 shows the Conventional Climb performance of generic Normal Category helicopters estimated for Levels I, II and III at various weights for standard day conditions at different altitudes; and Tables B-5A and B-5B show similar data for Transport Category helicopters. It can be seen that small differences in performance occur between helicopters at different maximum TOGW for corresponding conditions of performance level, altitude, and percentage of load. Inasmuch as these differences are small, the 6000 pound configuration of normal helicopter and 10,000 pound transport helicopter, representing the least capable of each class, have been selected for more detailed presentation of data in the main body of the report.

ESTIMATION OF CLIMB GRADIENT FOR DIRECT CLIMB IN WHICH CLIMBOUT IS INITIATED DIRECTLY FROM THE HOVER.

Estimation of capability to climb directly from a hover while accelerating into forward flight requires a different theoretical treatment and different data on which to base estimates. This process of estimation is based on the ability to climb vertically, an ability only achievable below the ceiling for HOGE. Figure B-2 shows the characteristics of power required to sustain level flight versus airspeed. A plateau exists from the hover, zero airspeed, out to some modest value of airspeed, typically of the order of 10 knots. Then, power required diminishes, but power available is not particularly sensitive to airspeed in these slow flight regimes and may be taken to be constant. The means taken to develop estimates of Direct Climb rely on this plateau of power required. It has been assumed that the vector sum of vertical rate of climb (zero forward airspeed) and forward airspeed up to the knee in the power required curve results in a power requirement

TABLE B-4

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES

NORMAL CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	I Percent Max. TOGW 100%	I 85%	I 70%	II Percent Max. TOGW 100%	II 85%	II 70%	III Percent Max. TOGW 100%	III 85%	III 70%
3,000 lbs. MAX TOGW										
S.L.	+15	6.15	4.99	3.80	3.51	2.93	2.27	2.47	2.06	1.57
2,500	+10	7.10	5.69	4.29	3.99	3.32	2.57	2.80	2.35	1.81
5,000	+ 5	8.28	6.53	4.87	4.56	3.77	2.91	3.19	2.67	2.07
7,500	0	9.77	7.56	5.54	5.24	4.30	3.30	3.64	3.04	2.36
10,000	- 5	11.73	8.84	6.35	6.06	4.92	3.75	4.17	3.47	2.68
4,500 lbs. MAX TOGW										
S.L.	+15	7.86	5.99	4.32	4.55	3.67	2.76	3.24	2.66	2.01
2,500	+10	9.41	6.99	4.94	5.27	4.20	3.14	3.72	3.04	2.30
5,000	+ 5	11.50	8.25	5.68	6.16	4.84	3.57	4.30	3.48	2.62
7,500	0	14.47	9.88	6.58	7.29	5.62	4.09	4.99	4.00	2.99
10,000	- 5	19.01	12.10	7.70	8.76	6.58	4.70	5.86	4.62	3.43
Up to 6,000 lbs. MAX TOGW										
S.L.	+15	10.23	7.23	4.93	5.62	4.35	3.17	3.98	3.18	2.36
2,500	+10	12.88	8.65	5.70	6.65	5.05	3.62	4.63	3.66	2.70
5,000	+ 5	16.97	10.58	6.65	8.02	5.92	4.16	5.44	4.23	3.09
7,500	0	23.95	13.29	7.86	9.87	7.03	4.81	6.48	4.93	3.55
10,000	- 5	38.72	17.42	9.43	12.54	8.48	5.61	7.84	5.81	4.10

TABLE B-5A

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	85%	70%	II Percent Max. TOGW 100%	85%	70%	III Percent Max. TOGW 100%	85%	70%
Over 6,000 lbs. MAX TOGW										
S.L.	+15	5.94	4.81	3.66	3.89	3.23	2.49	2.92	2.44	1.88
2,500	+10	6.86	5.49	4.13	4.43	3.66	2.82	3.32	2.77	2.14
5,000	+ 5	8.00	6.31	4.69	5.08	4.16	3.19	3.79	3.15	2.43
7,500	0	9.46	7.30	5.35	5.87	4.76	3.62	4.34	3.59	2.77
10,000	- 5	11.36	8.55	6.13	6.83	5.47	4.12	5.00	4.10	3.15
8,000 lbs. MAX TOGW										
S.L.	+15	6.57	5.20	3.87	4.34	3.54	2.70	3.28	2.76	2.07
2,500	+10	7.70	5.98	4.39	4.99	4.04	3.06	3.75	3.08	2.36
5,000	+ 5	9.15	6.95	5.01	5.78	4.63	3.47	4.31	3.52	2.68
7,500	0	11.06	8.16	5.75	6.76	5.33	3.96	4.98	4.03	3.05
10,000	- 5	13.70	9.71	6.65	8.01	6.19	4.53	5.80	4.64	3.49
10,000 lbs. MAX TOGW										
S.L.	+15	6.78	5.29	3.89	4.52	3.66	2.76	3.44	2.82	2.14
2,500	+10	8.01	6.12	4.43	5.23	4.18	3.14	3.95	3.22	2.44
5,000	+ 5	9.61	7.15	5.07	6.10	4.81	3.57	4.55	3.68	2.78
7,500	0	11.78	8.46	5.84	7.19	5.57	4.08	5.29	4.23	3.17
10,000	- 5	14.87	10.17	6.79	8.61	6.52	4.68	6.22	4.90	3.63

TABLE B-5B

CLIMB GRADIENTS FOR CONVENTIONAL CLIMB

STANDARD DAY TEMPERATURES

TRANSPORT CATEGORY HELICOPTERS

		PERFORMANCE LEVELS								
PRESSURE		I			II			III		
ALTITUDE	TEMP	Percent Max. TOGW			Percent Max. TOGW			Percent Max. TOGW		
(feet)	(°C)	100%	85%	70%	100%	85%	70%	100%	85%	70%
12,500 lbs. MAX TOGW										
S.L.	+15	6.51	5.07	3.72	4.43	3.57	2.69	3.40	2.78	2.10
2,500	+10	7.69	5.87	4.24	5.12	4.09	3.05	3.90	3.17	2.40
5,000	+ 5	9.23	6.87	4.86	5.99	4.71	3.48	4.52	3.64	2.73
7,500	0	11.32	8.12	5.60	7.08	5.46	3.98	5.26	4.19	3.12
10,000	- 5	14.31	9.77	6.51	8.50	6.40	4.58	6.19	4.85	3.58
15,000 lbs. MAX TOGW										
S.L.	+15	5.87	4.63	3.42	4.09	3.31	2.50	3.17	2.60	1.96
2,500	+10	6.89	5.34	3.90	4.72	3.76	2.84	3.64	2.97	2.24
5,000	+ 5	8.21	6.21	4.46	5.50	4.36	3.24	4.20	3.40	2.56
7,500	0	9.95	7.30	5.12	6.47	5.04	3.70	4.88	3.91	2.93
10,000	- 5	12.37	8.71	5.93	7.72	5.89	4.25	5.73	4.52	3.35
17,500 lbs. MAX TOGW										
S.L.	+15	5.10	4.08	3.06	3.64	2.97	2.25	2.85	2.35	1.77
2,500	+10	5.94	4.68	3.47	4.18	3.39	2.56	3.27	2.68	2.03
5,000	+ 5	6.99	5.42	3.96	4.84	3.89	2.92	3.76	3.07	2.32
7,500	0	8.33	6.31	4.54	5.65	4.88	3.33	4.35	3.52	2.66
10,000	- 5	10.13	7.45	5.23	6.67	5.20	3.82	5.07	4.06	3.04

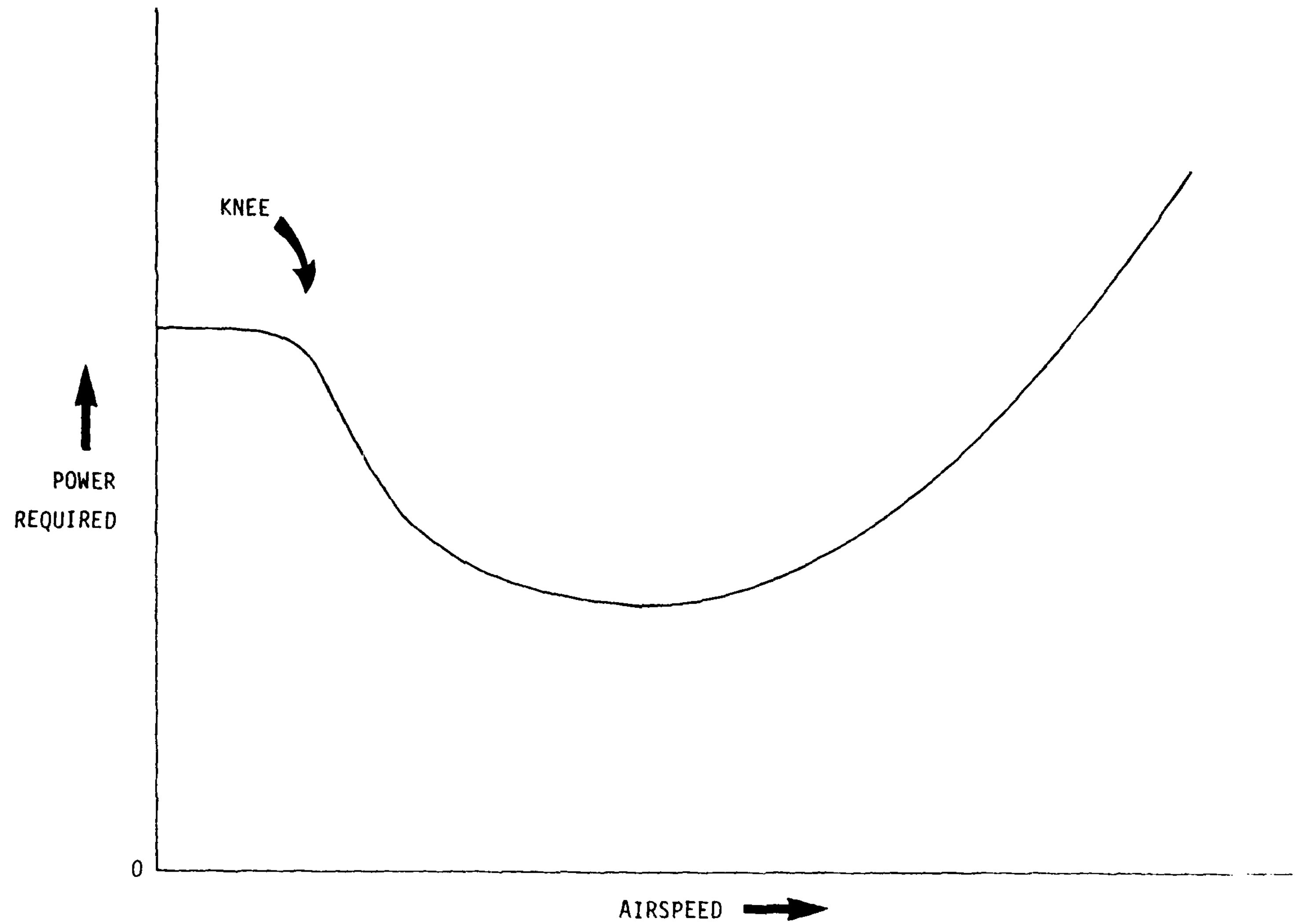


Figure B-2. Nature of Helicopter Power Required vs. Airspeed

equivalent to that needed solely for the vertical climb. Once the knee of the curve has been reached, power required to sustain level flight begins to noticeably diminish (effective translational lift has been achieved) and a larger increment of power becomes available to sustain the accelerating climb. Phrasing the assumptions differently, when power is available to permit a vertical climb rate to be sustained, a portion of that power may be used to accelerate into forward flight while concurrently climbing; upon reaching the flight velocity for "effective translational lift" (represented by the knee of the power required curve of Figure B-2) power available to sustain the climbing acceleration begins to increase. Inasmuch as the specific characteristics of curves such as in Figure B-2 are not published in RFM, it is necessary to develop estimates of related parameters.

An estimate of vertical climb capability is of paramount importance to Direct Climb estimation. To obtain this estimate we again appeal to momentum theory. Form Richards, the induced power required to hover is:

$$P_i = Wv_i = W\sqrt{\frac{W}{2\rho\pi R^2}}$$

At the limiting density altitude, $h_{d\,oge}$, for HOGE this becomes:

$$Wv_{i\,OGE} = \text{limit of power available} = \frac{W^{3/2}}{\sqrt{2\rho_{OGE}\pi R^2}}$$

If it is assumed the P_i is constant (except for corrections to compensate for increases in available power resulting form altitude reduction), the power available to climb, P_c, at some lower density altitude, $h_{d\ 2}$, is:

$$P_c = WV' = Wv_{i\ OGE} - Wv_{i\ 2}$$

Solving for the uncorrected vertical rate of climb, V', this becomes:

$$V' = v_{i\ OGE} - v_{i\ 2} = \sqrt{\frac{W}{2\ \rho_{OGE}\ \pi R^2}} - \sqrt{\frac{W}{2\ \rho_2\ \pi R^2}}$$

$$= \sqrt{\frac{W}{2\ \pi R^2}}\ \left(\frac{1}{\sqrt{\rho_{OGE}}} - \frac{1}{\sqrt{\rho_2}}\right) \qquad \text{Eqn. (5)}$$

Since the vertical motion of the helicopter permits the rotor to act on a greater mass of air than has been assumed in the momentum theory for hovering applied thus far, a correction will be developed based on the conservation of power, also from Richards:

$$W\left(v_{i\ 2} + V'\right) = W\left(v_{i\ v} + V_v\right) \qquad \text{Eqn. (6)}$$

in which $V_{i\ v}$ is the corrected induced velocity in vertical climb and V_v the corresponding correctecd rate of climb. From Richards, using the relationship:

$$v_i^2 = v_{i\ v}^2 + v_{i\ v}\ V_v$$

Equation (6) is solved non-dimensionally to yield:

$$\frac{V_v}{V'} = 1 + \frac{1}{1+V'/v_{i\,2}}$$

which yields V_v as follows in terms definable from RFM information:

$$V_v = V'\left(1 + \frac{1}{V'/v_{i_2} + 1}\right) \qquad \text{Eqn. (7)}$$

Combining Equations (5) and (7) yields:

$$V_v = \sqrt{\frac{W}{2\,\pi R^2}}\left(\frac{1}{\sqrt{\rho_{OGE}}} - \frac{1}{\sqrt{\rho_2}}\right)\left[1 + \left(\frac{1/\sqrt{\rho_{OGE}} - 1/\sqrt{\rho_2}}{1/\sqrt{\rho_2}} + 1\right)^{-1}\right]$$

$$= \sqrt{\frac{\rho_{OGE}}{2}} \cdot \sqrt{\frac{W}{\pi R^2}}\left(\frac{1}{\rho_{OGE}} - \frac{1}{\rho_2}\right) \qquad \text{Eqn. (8)}$$

This expression is reasonably accurate for small differences between $h_{d\ oge}$ and $h_{d\ 2}$. It improves as such differences diminish providing the most accurate estimate of capability for the most critical flight regime. The estimate is limited to the extent that the vertical component of drag is neglected. This component is least significant at the limiting, lowest rates of vertical climb.

In order to correct for increases in available power at lower altitude, V_v has been further modified to reflect differences in pressure altitude by:

$$V_v' = \frac{\delta_2}{\delta_{OGE}} V_v \qquad \text{Eqn. (9)}$$

The data presented in the main body of the report were computed from HOGE limits based on standard, +10°C, +20°C and +30°C temperatures. In this way no further correction need be made for temperature. If RFM data are not availabe for the increment of temperature, T , difference from standard conditions, the same correction factor developed in the Direct Climb section could be applied such that:

$$V_v'' = \frac{288}{288+2.5\,\Delta T} V_v'$$

This correction was not needed for data in this report.

To estimate the climb gradient realizable from vertical rates of climb computed from Equation (9), 10 Knots horizontal velocity component V_h has been arbitrarily assumed to coincide with the estimated vertical velocity. Consequently, the estimated direct climb gradient can be directly computed as:

$$\text{gradient} = V_h/V_v'$$

(in appropriate units).

Table B-6 shows the acceleration Direct Climb of generic Normal Category helicopters estimated for Levels I, II and III at various weights for standard day conditions at different altitudes; and Tables B-7A and B-7B show similar data for Transport Category helicopters. It can be seen that small differences in performance occur between helicopters at different maximum TOGW for conditions of performance level, altitude, and percentage of load. Inasmuch as these differences are small, the 3000 pound configuration of Normal Category helicopter and 6000 pound Transport Category helicopter, representing the least capable of each class, have been selected for more detailed presentation of data in the main body of the report.

TABLE B-6

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES

NORMAL CATEGORY HELICOPTERS

		PERFORMANCE LEVELS								
PRESSURE		I			II			III		
ALTITUDE	TEMP	Percent Max. TOGW			Percent Max. TOGW			Percent Max. TOGW		
(feet)	(°C)	100%	90%	80%	100%	90%	80%	100%	90%	80%
3,000 lbs. MAX TOGW										
S.L.	+15	35.76	3.34	2.15	3.55	1.47	0.93	1.40	0.82	0.48
2,500	+10	NC	6.41	3.25	7.42	2.04	1.18	1.94	1.03	0.58
5,000	+ 5	NC	41.22	6.16	NC	3.17	1.57	3.01	1.36	0.70
7,500	0	NC	NC	33.00	NC	6.40	2.26	6.07	1.91	0.85
10,000	- 5	NC	NC	NC	NC	89.67	3.75	85.07	3.03	1.14
4,500 lbs. MAX TOGW										
S.L.	+15	30.80	2.88	1.85	3.06	1.27	0.80	1.20	0.71	0.42
2,500	+10	NC	5.53	2.80	6.39	1.76	1.02	1.67	0.89	0.50
5,000	+ 5	NC	35.51	5.30	NC	2.73	1.36	2.59	1.13	0.60
7,500	0	NC	NC	28.43	NC	5.52	1.95	5.23	1.64	0.76
10,000	- 5	NC	NC	NC	NC	77.25	3.23	73.28	2.61	0.98
6,000 lbs. MAX TOGW										
S.L.	+15	28.14	2.63	1.69	2.79	1.16	0.23	1.10	0.64	0.38
2,500	+10	NC	5.05	2.56	5.84	1.61	0.93	1.52	0.81	0.45
5,000	+ 5	NC	32.44	4.85	NC	2.50	1.24	2.37	1.07	0.55
7,500	0	NC	NC	25.97	NC	5.04	1.28	4.78	1.50	0.69
10,000	- 5	NC	NC	NC	NC	70.58	2.95	66.96	2.39	0.90

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TABLE B-7A

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I: Percent Max. TOGW 100%	I: 90%	I: 80%	II: Percent Max. TOGW 100%	II: 90%	II: 80%	III: Percent Max. TOGW 100%	III: 90%	III: 80%
6,000 lbs. MAX TOGW										
S.L.	+15	5.95	3.62	1.94	2.23	1.26	0.89	0.86	0.64	0.49
2,500	+10	171.97	9.33	3.09	4.01	1.79	1.16	1.14	0.80	0.59
5,000	+ 5	NC	NC	6.77	14.77	2.89	1.61	1.63	1.05	0.74
7,500	0	NC	NC	NC	NC	6.63	2.50	2.66	1.47	0.96
10,000	- 5	NC	NC	NC	NC	NC	5.08	6.31	2.33	1.32
8,000 lbs. MAX TOGW										
S.L.	+15	5.54	3.37	1.81	2.08	1.17	0.82	0.80	0.59	0.45
2,500	+10	159.95	8.68	2.88	3.73	1.66	1.08	1.06	0.75	0.55
5,000	+ 5	NC	NC	6.30	13.74	2.69	1.50	1.52	0.98	0.69
7,500	0	NC	NC	NC	NC	6.17	2.33	2.48	1.37	0.89
10,000	- 5	NC	NC	NC	NC	NC	4.73	5.87	2.16	1.23
10,000 lbs. MAX TOGW										
S.L.	+15	5.32	3.23	1.74	2.00	1.13	0.79	0.77	0.57	0.43
2,500	+10	153.66	8.33	2.76	3.58	1.60	1.03	1.02	0.72	0.53
5,000	+ 5	NC	NC	6.05	13.20	2.59	1.44	1.46	0.94	0.66
7,500	0	NC	NC	NC	NC	5.93	2.24	2.38	1.32	0.86
10,000	- 5	NC	NC	NC	NC	NC	4.54	5.64	2.08	1.18

TABLE B-7B

CLIMB GRADIENTS FOR DIRECT CLIMB

STANDARD DAY TEMPERATURES

TRANSPORT CATEGORY HELICOPTERS

PRESSURE ALTITUDE (feet)	TEMP (°C)	PERFORMANCE LEVELS I Percent Max. TOGW 100%	I 90%	I 80%	II Percent Max. TOGW 100%	II 90%	II 80%	III Percent Max. TOGW 100%	III 90%	III 80%
12,500 lbs. MAX TOGW										
S.L.	+15	5.20	3.16	1.60	1.95	1.10	0.73	0.76	0.56	0.40
2,500	+10	150.26	8.15	2.55	3.50	1.56	0.95	1.00	0.70	0.49
5,000	+ 5	NC	NC	5.58	12.90	2.53	1.33	1.42	0.92	0.61
7,500	0	NC	NC	NC	NC	5.80	2.06	2.33	1.29	0.79
10,000	- 5	NC	NC	NC	NC	NC	4.19	5.52	2.03	1.09
15,000 lbs. MAX TOGW										
S.L.	+15	5.19	3.16	1.69	1.95	1.10	0.77	0.75	0.56	0.42
2,500	+10	149.98	8.13	2.70	3.50	1.56	1.01	1.00	0.70	0.52
5,000	+ 5	NC	NC	5.90	12.88	2.52	1.40	1.42	0.92	0.65
7,500	0	NC	NC	NC	NC	5.79	2.18	2.32	1.29	0.84
10,000	- 5	NC	NC	NC	NC	NC	4.43	5.51	2.03	1.15
17,500 lbs. MAX TOGW										
S.L.	+15	5.25	3.20	1.72	1.97	1.11	0.78	0.76	0.56	0.43
2,500	+10	151.81	8.23	2.73	3.54	1.58	1.02	1.01	0.71	0.52
5,000	+ 5	NC	NC	5.98	13.04	2.55	1.42	1.44	0.93	0.65
7,500	0	NC	NC	NC	NC	5.86	2.21	2.35	1.30	0.85
10,000	- 5	NC	NC	NC	NC	NC	4.49	5.57	2.05	1.17

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